LOAN DOCUMENT

PHOTOGRAPH THIS SHEET

LEVEL

1

INVENTORY

DTIC ACCESSION NUMBER

RIA-78-U703

DOCUMENT IDENTIFICATION

27 Jul 1960

DISTRIBUTION STATEMENT A

"[redacted] Approved for Public Release

Distribution Unlimited

DISTRIBUTION STATEMENT

H A N D L E W I T H C A R E

ACCESSION FOR

NTIS GRA&I

DTIC TRAC

UNANNOUNCED

JUSTIFICATION

BY

DISTRIBUTION/

AVAILABILITY CODES

DISTRIBUTION	AVAILABILITY AND/OR SPECIAL	
A-1		

DISTRIBUTION STAMP

DATE ACCESSIONED

DATE RETURNED

19990517 083

DATE RECEIVED IN DTIC

REGISTERED OR CERTIFIED NUMBER

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-FDAC

DTIC FORM JUN 90 70A

DOCUMENT PROCESSING SHEET

PREVIOUS EDITIONS MAY BE USED UNTIL STOCK IS EXHAUSTED.

LOAN DOCUMENT

384

ON AGAINST RADIATIONS
FROM SEALED GAMMA SOURCES

Handbook 73

U.S. Department of Commerce
National Bureau of Standards

HANDBOOKS OF THE NATIONAL BUREAU OF STANDARDS

The following Handbooks issued by the Bureau are available by purchase from the Superintendent of Documents, Government Printing Office, Washington 25, D.C., at the prices indicated:

No.		Price
28	Screw-Thread Standards for Federal Services 1944	$1.25
28	1950 Supplement to Screw-Thread Standards for Federal Services 1944	.60
28	Screw-Thread Standards for Federal Services 1957, Part I (Amends in part H28 1944 and in part its 1950 Supplement)	1.25
28	Screw-Thread Standards for Federal Services 1957, Part II	.75
30	National Electrical Safety Code	2.25
37	Testing of Weighing Equipment	2.50
42	Safe Handling of Radioactive Isotopes	.20
43	Installation and Maintenance of Electric Supply and Communication Lines. Safety Rules and Discussion	2.25
44	Specifications, Tolerances, and Regulations for Commercial Weighing and Measuring Devices—2d Edition	2.00
45	Testing of Measuring Equipment	1.50
48	Control and Removal of Radioactive Contamination in Laboratories	.15
49	Recommendations for Waste Disposal of Phosphorus-32 and Iodine-131 for Medical Users	.15
50	X-ray Protection Design	.20
51	Radiological Monitoring Methods and Instruments	.20
53	Recommendations for the Disposal of Carbon-14 Wastes	.15
54	Protection Against Radiations from Radium, Cobalt-60, and Cesium-137	.25
55	Protection Against Betatron-Synchrotron Radiations up to 100 Million Electron Volts	.25
57	Photographic Dosimetry of X- and Gamma Rays	.15
58	Radioactive-Waste Disposal in the Ocean	.20
59	Permissible Dose From External Sources of Ionizing Radiation	.35
60	X-ray Protection	.20
61	Regulation of Radiation Exposure by Legislative Means	.25
62	Report of the International Commission on Radiological Units and Measurements (ICRU) 1956	.40
63	Protection Against Neutron Radiation up to 30 Million Electron Volts	.40
64	Design of Free-Air Ionization Chambers	.20
65	Safe Handling of Bodies Containing Radioactive Isotopes	.15
66	Safe Design and Use of Industrial Beta-Ray Sources	.20
67	Checking Prepackaged Commodities	.35
68	Tabulation of Data on Receiving Tubes	1.00
69	Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure	.35
72	Measurement of Neutron Flux and Spectra for Physical and Biological Applications	
73	Protection Against Radiations From Sealed Gamma Sources	.30

U.S. Department of Commerce • Frederick H. Mueller, Secretary
National Bureau of Standards • A. V. Astin, Director

Protection Against Radiations From Sealed Gamma Sources

Recommendations of the
National Committee on Radiation Protection
and Measurements
NCRP Report No. 24

National Bureau of Standards Handbook 73
Issued July 27, 1960

[Supersedes H54]

~~For sale by the Superintendent of Documents, Washington 25, D.C. - Price 30 cents~~

Preface

One of the primary considerations leading to the preparation of this handbook as a revision of the old Handbook 54 has been the modification of the recommendations of the maximum permissible radiation exposure to man. These have been published as an addendum to Handbook 59 on April 15, 1958. Essentially, the same modifications have been adopted by the International Commission on Radiological Protection.

The pattern of the present handbook follows fairly closely that of its predecessor Handbook 54. However, advantage has been taken of new knowledge and information gained since the publication of the earlier handbook. At that time, our experience with teletherapy protection problems was limited as there were only a few kilocurie installations in use in 1954. Since that time, however, a large number of different types of gamma beam equipment has been put into operation and more extensive data have been obtained on the stray radiation received by the patient and personnel. As a result, it was found desirable to be more specific regarding the shielding requirements of the source housing, particularly relating to the permissible leakage radiation with the beam control in the "on" position.

Revisions have been made also with the aim of securing greater uniformity among the various handbooks, particularly where these cover very similar subjects as is the case of Handbooks 54 and 60. A greater distinction has been made in the present handbook between mandatory recommendations and those which are advisory only. Although the objective of the NCRP recommendations is to provide authoritative information rather than the material to be used for legislative purposes, several states and local authorities have based their protection codes on the NBS handbooks. This has been considered in the present handbook by limiting the mandatory provisions to those considered absolutely essential for adequate protection; the term "shall" has been used for such recommendations. The term "should" has been used in conjunction with advisory recommendations which, in many cases, would be desirable but not always essential to ensure adequate protection. If such recommendations were made mandatory, they might unnecessarily make some of the present installations obsolete.

The present handbook and its predecessors stem from the Second International Congress of Radiology, held in Stockholm in 1928. At that time, under the auspices of the Congress, the International Commission on Radiological

Protection (ICRP) was organized to deal initially with problems of X-ray protection and later with radioactivity protection. At that time "permissible" doses of X-rays were estimated primarily in terms of exposures which produced erythema, the amount of exposure which would produce a defined reddening of the skin. Obviously, a critical problem in establishing criteria for radiation protection was one of developing useful standards and techniques of physical measurement. For this reason, two of the organizations in this country with a major concern for X-ray protection, the American Roentgen Ray Society and the Radiological Society of North America, suggested that the National Bureau of Standards assume responsibility for organizing representative experts to deal with the problem. Accordingly, early in 1929, the Advisory Committee on X-ray and Radium Protection was organized to develop recommendations on the protection problem within the United States and to formulate United States points of view for presentation to the International Commission on Radiological Protection. The organization of the U.S. Advisory Committee included experts from both the medical and physical science fields.

As a result of the extensive developments immediately preceding and during World War II that added substantially to the importance of radiation protection problems, the Advisory Committee was reorganized in 1946 as the National Committee on Radiation Protection (and later, the National Committee on Radiation Protection and Measurements—NCRP). The revised Committee included representation from the various professional societies with an interest in the problem, government agencies with related interest and responsibilities, as well as individual experts. The continued administrative sponsorship of the Committee by the National Bureau of Standards was in accordance with its statutory responsibility to cooperate with other governmental agencies and with private organizations in the development of standard practices, incorporated in codes and specifications. In addition, the recommendations of the National Committee on Radiation Protection and Measurements have been published as handbooks by the National Bureau of Standards, again in accordance with its statutory authorizations.

The National Committee on Radiation Protection and Measurements is governed by representatives of 18 participating organizations, including the National Bureau of Standards. Eighteen subcommittees have been established, each charged with the responsibility of preparing recommendations on its particular field. The reports of the subcommittees are approved by the main committee before publication.

The following parent organizations and individuals comprise the main committee:

H. L. Andrews, U.S. Public Health Service and Subcommittee Chairman.
E. C. Barnes, American Industrial Hygiene Association.
C. M. Barnes, American Veterinary Medical Association.
John P. O'Neill, International Association of Government Labor Officials.
C. B. Braestrup, Radiological Society of North American and Subcommittee Chairman.
J. C. Bugher, Representative-at-large.
R. H. Chamberlain, American College of Radiology.
W. D. Claus, U.S. Atomic Energy Commission.
C. L. Dunham, U.S. Atomic Energy Commission.
T. P. Eberhard, American Radium Society and Subcommittee Chairman.
T. C. Evans, American Roetgen Ray Society.
G. Failla, Representative-at-large.
J. W. Healy, Health Physics Society and Subcommittee Chairman.
P. C. Hodges, American Medical Association.
E. R. King, Capt., U.S. Navy.
M. Kleinfeld, International Association of Government Labor Officials.
H. W. Koch, Subcommittee Chairman.
G. V. LeRoy, Subcommittee Chairman.
D. I. Livermore, Lt. Col., U.S. Air Force.
W. B. Mann, Subcommittee Chairman.
W. A. McAdams, Atomic Industrial Forum and Subcommittee Chairman.
G. M. McDonnel, Lt. Col., U.S. Army.
G. W. Morgan, Subcommittee Chairman.
K. Z. Morgan, Health Physics Society and Subcommittee Chairman.
R. J. Nelsen, American Dental Association.
R. R. Newell, American Roetgen Ray Society.
W. D. Norwood, Industrial Medical Association.
C. Powell, U.S. Public Health Service.
E. H. Quimby, American Radium Society and Sudcommittee Chairman.
J. A. Reynolds, National Electrical Manufacturers Association.
H. H. Rossi, Subcommittee Chairman.
M. D. Schulz, American College of Radiology.
T. L. Shipman, Industrial Medical Association.
L. S. Skaggs, Subcommittee Chairman.
J. H. Sterner, American Industrial Hygiene Association.
R. S. Stone, Radiological Society of North American.
L. S. Taylor, National Bureau of Standards.
E. D. Trout, National Electrical Manufacturers Association.
B. F. Trum, American Veterinary Medical Association.
Shields Warren, Representative-at-large.
J. L. Weatherwax, Representative-at-large.
E. G. Williams, Representative-at-large.
H. O. Wyckoff, Subcommittee Chairman.

The following are the subcommittees and their chairman:

Subcommittee 1.	Permissible Dose from External Sources. (Responsibility of the Executive Committee.) H. M. Parker.
Subcommittee 2.	Permissible Internal Dose, K. Z. Morgan.
Subcommittee 3.	X-rays up to Two Million Volts, T. P. Eberhard.
Subcommittee 4.	Heavy Particles (Neutrons, Protons, and Heavier), H. H. Rossi.
Subcommittee 5.	Electrons, Gamma Rays and X-rays Above Two Million Volts, H. W. Koch.
Subcommittee 6.	Handling of Radioactive Isotopes and Fission Products, J. W. Healy.
Subcommittee 7.	Monitoring Methods and Instruments, H. L. Andrews.
Subcommittee 8.	Waste Disposal and Decontamination. (This subcommittee has been inactivated.)
Subcommittee 9.	Protection Against Radiations from Radium, Cobalt–60, and Cesium–137 Encapsulated Sources, C. B. Braestrup.
Subcommittee 10.	Regulation of Radiation Exposure Dose, W. A. McAdams.
Subcommittee 11.	Incineration of Radioactive Waste, G. W. Morgan.
Subcommittee 12.	Electron Protection, L. S. Skaggs.
Subcommittee 13.	Safe Handling of Bodies Containing Radioactive Isotopes, E. H. Quimby.
Subcommittee 14.	Permissible Exposure Doses Under Emergency Conditions, G. V. LeRoy.
Subcommittee M–1.	Standards and Measurement of Radioactivity for Radiological Use, W. B. Mann.
Subcommittee M–2.	Standards and Measurement of Radiological Exposure Dose, H. O. Wyckoff.
Subcommittee M–3.	Standards and Measurement of Absorbed Raation Dose, H. O. Wyckoff.
Subcommittee M–4.	Relative Biological Effectiveness, V. P. Bond

The present handbook was prepared by the Subcommittee on Protection Against Radiations from Radium, Cobalt–60, and Cesium–137.

C. B. BRAESTRUP, Chairman.	J. R. MASON.
H. BLATZ.	E. H. QUIMBY.
M. BRUCER.	E. L. SAENGER.
T. P. EBERHARD.	W. K. SINCLAIR.
G. FERLAZZO.	H. O. WYCKOFF.

A. V. ASTIN, *Director*.

Contents

Protection Against Radiations From Sealed Gamma Sources

1. Definitions

Terms in this report will be used in accordance with the following brief definitions:

Shall denotes that the ensuing recommendation is necessary or essential to meet the currently accepted standards of protection.

Should, is recommended, indicates advisory recommendations that are to be applied when practicable.

Absorbed dose. Energy imparted to matter by ionizing particles per unit mass of irradiated mateıial at the place of interest. The unit of absorbed dose is the *rad.* (When the meaning is clear, this term may be shortened to "dose".)

Activity. The number of atoms decaying per unit of time.

Attenuation. Decrease in dose rate caused by the passage of radiation through material.

Background radiation. Radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There may also be background radiation due to the presence of radioactive substances in other parts of the building, in the building material itself, etc.

Barrier. See *protective barrier.*

Beta particles (beta rays). Electrons, positive or negative, emitted during radioactive disintegration.

Concrete equivalent. The thickness of concrete of density 2.35 g/cm^3 (147 lb/ft^3) affording the same attenuation, under specified conditions, as the material in question.

Contamination (radioactive). Deposition of radioactive material in any place where it is not desired, and particulary in any place where its presence can be harmful. The harm may be in vitiating the validity of an experiment or a procedure, or in actually being a source of danger to persons.

Controlled area. A defined area in which the occupational exposure of personnel to radiation or to radioactive material is under the supervision of an individual in charge of radiation protection. (This implies that a controlled area is one that requires control of access, occupancy, and working conditions for radiation protection purposes.)

Curiage. The number of curies (kilocuries, millicuries, microcuries).

Curie (c). A unit of activity defined as the quantity of any radioactive nuclide in which the number of disintegrations per second is 3.700×10^{10}.

Decay, radioactive. Spontaneous change of a nucleus with emission of a particle or a photon; rate of decay is usually expressed in terms of *half life*.

Dose. See *absorbed dose, exposure dose,* and *RBE dose.*

Dose rate. Dose per unit time.

Dose-rate meter. Instrument for measuring dose rate.

Dosimeter. Instrument for measuring total dose.

Exposure. See *exposure dose.*

Exposure dose. The exposure dose of X- or gamma radiation at a certain place is a measure of the radiation that is based upon its ability to produce ionization in air. The unit of exposure dose is the *roentgen*. (When the meaning is clear, this term may be shortened to "exposure.")

Exposure dose rate (exposure rate). Exposure dose per unit time.

Film badge. A pack of appropriate photographic film and filters used to determine radiation exposure.

Gamma rays. Electromagnetic radiation of short wavelength and correspondingly high frequency, emitted by nuclei in the course of radioactive decay.

Half life, radioactive. Time for the activity of any particular radioisotope to be reduced to half its initial value.

Half-value layer (HVL). Thickness of an absorber required to attenuate a beam of radiation to one-half.

Hazard, radiation. See *radiation hazard.*

Installation. A radiation source, with its associated eqiupment, and the space in which it is located.

Interlock. A device for precluding access to an area of radiation hazard either by preventing entry or by automatically removing the hazard.

Isotope. One of several different atoms of a particular element, having the same number of protons in their nuclei, and hence having the same atomic number, but differing in the number of neutrons and hence in the mass number.

Lead equivalent. The thickness of lead affording the same attenuation, under specified conditions, as the material in question.

Leakage radiation. See *Radiation.*

Maximum permissible dose (MPD). The maximum RBE dose that the body of a person or specific parts thereof shall be permitted to receive in a stated period of time. For the radiations considered here, the RBE dose in rems may be considered numerically equal to the absorbed dose in rads and the exposure dose in roentgens numerically equal to the absorbed dose in rads. (See table 1, appendix A.)

Microcurie (μc). One-millionth of a curie (3.700×10^4 disintegrations per second).

Millicurie (mc). One-thousandth of a curie (3.700×10^7 disintegrations per second).

Million electron volts (Mev). Energy equal to that acquired by a particle with one electronic charge in passing through a potential difference of one million volts (one Mv).

Millirad (mrad). One-thousandth of a rad.

Milliroentgen (mr). One-thousandth of a roentgen.

Monitoring. Periodic or continuous determination of the exposure rate in an area (area monitoring) or the exposure received by a person (personnel monitoring) or the measurement of contamination levels.

Occupancy factor (T). The factor by which the workload should be multiplied to correct for the degree or type of occupancy of the area in question.

Occupied area. An area that may be occupied by persons or radiation-sensitive materials.

Pocket chamber. A small condenser ionization chamber used for determining radiation exposure. An auxiliary charging and reading device is usually necessary.

Pocket dosimeter. A small ionization instrument which indicates radiation exposure directly. An auxiliary charging device is usually necessary.

Protective barrier. Barrier of attenuating material used to reduce radiation hazards.

Primary protective barrier. Barrier sufficient to attenuate the useful beam to the required level.

Secondary protective barrier. Barrier sufficient to attenuate stray radiation to the required level.

Qualified expert. A person having the knowledge and training necessary to measure ionizing radiations and to advise regarding radiation protection.

Rad. Unit of absorbed dose. 1 rad is 100 ergs/g.

Radiation. Energy propagated through space. As commonly employed in radiology, the term refers to two kinds of ionizing radiation: (1) Electromagnetic waves (X-rays, gamma rays), and (2) corpuscular emissions from radioactive substances or other sources (alpha and beta particles, etc.). *Leakage radiation.* All radiation coming from the source, except the useful beam. *Primary radiation.* Radiation coming directly from the source. *Scattered radiation.* Radiation that, during passage through matter, has been deviated in direction and usually has also had its energy diminished.

Secondary radiation. Radiation emitted by any irradiated material. *Stray radiation.* Radiation not serving any useful purpose; includes leakage and scattered radiation. *Useful beam.* The radiation that passes through the window, aperture, cone, or other collimating device of the source housing.

Radiation hazard. A condition under which persons might receive radiation in excess of the applicable maximum permissible dose, or where radiation damage might be caused to materials.

Radiation protection (safety) officer. Person directly responsible for radiation protection. It is his duty to insure that all procedures are carried out in compliance with pertinent established rules, including recommendations contained in this Handbook.

Radiation protection survey. Evaluation of the radiation hazards in and around an installation. It customarily includes a physical survey of the arrangement and use of the equipment and measurements of the exposure rates under expected operating conditions.

Radioisotope. A radioactive nuclide.

RBE (relative biological effectiveness). RBE is used to compare the effectiveness of absorbed doses of radiation of different types. For protection purposes certain values of RBE have been agreed upon.

RBE dose. RBE dose for protection purposes is the product of the absorbed dose in rads and the RBE. The unit of RBE dose is the *rem*.

Rem. Unit of RBE dose.

Rhm. Roentgens per hour at one meter from the effective center of the source. (In teletherapy this distance is usually measured to the nearest surface of the source as its effective center generally is not known.)

Roentgen (r). Unit of exposure dose of X- or gamma radiation. One roentgen is an exposure dose of X- or gamma radiation such that the associated corpuscular emission per 0.001293 g of air produces, in air, ions carrying 1 esu of quantity of electircity of either sign.

Sealed source. Radioactive material that is encased in, and is to be used in, a container in a manner intended to prevent leakage of the radioactive material.

Source. Discrete amount of radioactive material or radiation-producing equipment.

Specific gamma-ray emission. Specific gamma-ray emission (specific gamma-ray output) of a radioactive nuclide is the exposure dose rate produced by the unfiltered gamma rays from a point source of a defined quantity of that nuclide at a defined distance. The unit of specific gamma-ray emission is the roentgen per millicurie hour at 1 cm.

Tenth-value layer (TVL). Thickness of an absorber required to attenuate a beam of radiation to one-tenth.

Teletherapy. Therapeutic irradiation with collimated gamma rays.

Use factor (U). The fraction of the workload during which the useful beam is pointed in the direction under consideration.

Useful beam. See *radiation.*

User. A person, organization, or institution having administrative control over one or more installations or mobile sources.

Workload. Total weekly exposure dose of the useful beam at 1 m from the nearest surface of the source (r/week at 1 m).

2. General Consideration

2.1. Scope

The present Handbook deals with protection against sealed gamma-ray sources and with discrete gamma-emitting sources that are not technically "sealed" but that may be treated in the same manner. The former include radium, radon seeds, cobalt-60, and cesium-137; other isotopes will doubtless become available for this type of source. Sources usually not technically sealed include cobalt-60 alloys, iridium-192 and gold-198 wires and seeds; here also others will probably be developed. The general principles outlined are applicable to all sources of these types. No specific references are made to industrial applications; however, the basic principles and the attenuation data of this Handbook are applicable to both medical and industrial uses.

Recommendations given here are not meant to restrict or inhibit the development of new designs for source housings or barriers. Their purpose is to afford guides to the amount of protection necessary in a given situation, and to set out in detail one method of achieving it.

2.2. Hazards

2.21. Hazards to be considered in the use and storage of radium and other radioactive substances may be classified as:

(a) Those harmful to human beings (either engaged in work with the radioactive substance or simply staying near it).

(1) Radiation originating outside the body.

(2) Radiation originating inside the body.

(b) Those that interfere with functioning of equipment, or damage to material sensitive to radiation (photographic films).

(1) Contamination.

(2) Increase of background.

2.22. Injury to human beings may result from overexposure to beta and gamma rays from sealed sources; should the sealed source be broken there is a possibility of radioactive contamination of the skin by spilled material; of accidental ingestion or inhalation of these substances; or of other modes of entry of the substances, such as cuts, punctures, and abrasions.

Overexposure may occur either from working with radioactive materials under unsuitable conditions, or from habitual occupation of a position too close to the material in inadequately shielded storage. In the former case, the injury is likely to be local on the fingers and hands; in the latter it will probably be systemic.

Habitual or long-continued *over*exposure to the hands may result in dry reddened skin, which cracks easily and is very sensitive to heat and cold. The nails become brittle, keratoses form near them, small cracks may ulcerate. These ulcers, or any other sores, heal slowly. Cancer may develop in the keratoses or ulcers. (Of course, proper protective measures should be taken long before this stage is reached.) Overexposure of the entire body may lead to depression of bone marrow activity or leukemia. The occurrence of permanent sterility is extremely unlikely.

Contamination of the skin by intimate contact with radioactive material may produce a local reaction sufficiently intense to result in erythema and desquamation. The local effect would be due mainly to beta radiation, and healing would be expected to occur without sequelae if prompt and effective measures were taken to remove as much of the material as possible. However, repeated contamination of this type might well lead to irreversible damage.

Ingestion, inhalation, or absorption of the material may give rise first to whole-body irradiation; followed by prolonged local irradiation if a long-lived substance is deposited in a particular region, as in the bones. Radium, mesothorium, and possibly other alpha-particle emitters are most dangerous, because of the very intense local irradiation to their preferential sites of deposit, as for example to bone or lung. Some radionuclides that are not alpha-emitters are also "boneseekers," and not well eliminated. The result is that even a small quantity of these materials, retained in the body, may lead to depression of bone marrow activity, and to serious bone lesions. Other isotopes generally are much more readily eliminated and thus do not consitute so great a hazard. Inhalation of radon from damaged radium containers may result in the deposit within the body of the decay products of the radon.

2.23. Permissible external radiation levels for long-term *occupational* exposure and for occasional exposure are discussed in detail in the report of the Subcommittee on Permissible Dose from External Sources [15].[1]

Permissible dose shall apply to the total dose to which a person is exposed *exclusive* of therapeutic and diagnostic irradiation. This is an important consideration in cases of simultaneous and separate exposures to more than one source of ionizing radiation. See table 1, appendix A for a summary of the permissible doses.

2.24. The presence of undesired radiation may interfere with functioning of equipment. If radiation reaches X-ray or photographic films, it may render them partially or totally useless. It may raise the background in the vicinity of radiation detecting and measuring instruments to such a high level that satisfactory operation is impossible. Contamination of these instruments by radioactive material from defective capsules may render them permanently useless.

2.3. Basic Principles of Radiation Protection

2.31. The ultimate purpose of all radiation-protection measures is to prevent the dose received by persons from exceeding the applicable maximum permissible levels, and to prevent damage or impairment of function of radiation-sensitive films, other objects, and instruments. This may be achieved by any one, or a combination, of the following factors: (a) increasing the working *distance* from the source of radiation, (b) reducing the *time* of exposure, and (c) interposing attenuating (protective) *barriers* between the source of radiation and persons or objects. The first of the *fundamental factors*, the distance, includes the inverse square

[1] Figures in brackets indicate the literature references listed in section 10.

law [2] and to a lesser extent the reduction due to the air absorption. The air absorption is small for gamma radiations considered here but is very large for particulate radiation (see table 2 in appendix B).

2.32. Table 2 shows the types and energies of radiations emitted by the sources considered in this Handbook together with the ranges of the particulate radiations. Because of the short ranges of alpha particles, no protection ordinarily is required against them when the source remains intact.[3] While beta particles have considerably longer paths in air than alpha particles, they are easily stopped by thin layers of metal or plastic.[4] Usually such a layer is incorporated in the capsule sealing a gamma-ray source. Protection against gamma rays, because of their much greater penetration, requires more detailed consideration and the barriers required are much more expensive.

2.33. The computation of the gamma shielding requirements may be simplified by considering separately: (a) the useful beam, (b) the radiation transmitted through the source shield (leakage radiation), and (c) the scattered radiation.[5]

2.34. *Useful beam.* The primary-protective-barrier thickness may be obtained from figures 6, 7, and 8 if the permissible transmission of radiation is known.

The permissible transmission, B, may be calculated from

$$B=\frac{Pd^2}{WUT(3.28)^2}=\frac{0.1Pd^2}{WUT} \qquad (1)$$

where

P is the permissible average weekly exposure (in roentgens) for design purposes, having a value of 0.1 r for controlled areas and 0.01 r for the environs,

d is the distance from source to the position in question (in feet),

W is the weekly exposure in the useful beam at 1 m from the source (obtained by multiplying the roentgens per minute

---

[2] The statement that the exposure rate from a source varies as the inverse square of the distance from the source assumes that the absorption of the intervening medium is negligible and that the source and detector dimensions are small (for practical purposes one-fifth the distance).

[3] See NCRP (NBS) Handbook 69 for permissible body burden.

[4] Some materials such as certain types of glass and plastic deteriorate under the action of particulate radiation.

[5] Equations (1) to (3) and the pertinent attenuation curves give the thickness of barrier when the radiation is incident normal to the surface. When the radiation is incident obliquely to the surface at an angle θ, the thickness of the barrier may not be equal to the thickness given by the equations and curves multiplied by the cosine . for very oblique angles [7].

If more than one source will produce appreciable radiation in the occupied area, then all such sources must be considered in the barrier design.

at 1 m by the weekly irradiation time in minutes, averaged over a year),

T is the occupancy factor, the fraction of the yearly irradiation time during which a person is exposed (see table 3, appendix B),

U is the use factor, the fraction of the workload during which the useful beam is pointed in the direction under consideration, and

3.28 is the conversion from meters to feet.

2.35. *Leakage radiation.* Equation (1) may be used to compute the barrier requirements for this radiation, where W is the leakage radiation in roentgens per week measured at 1 m from the source, and U is equal to 1.

2.36. *Scattered radiation.* Radiation scattered from an irradiated object has a lower dose rate and is softer (of lower energy) than the incident beam. Both the energy and dose rate of the scattered beam vary with the angle of scattering and atomic number of the scatterer. Figures 9 and 10 show the variation of $B_s \times (D_s/D_u)$ with barrier thickness, where B_s is the fractional transmission of the barrier, D_s is the unattenuated dose in the scattered beam at 1 m from the scatterer, and D_u is the dose incident on the scatterer. If the scatterer is at 1 m from the source and the field diameter is that given in the curves of figures 9 and 10

$$B_s \times \frac{D_s}{D_u} = \frac{0.1Pd^2}{WT}. \tag{2}$$

If the scatterer is at 50 cm from the source and the field diameter is that given in the curves of figures 9 and 10

$$B_s \times \frac{D_s}{D_u} = \frac{0.025Pd^2}{WT} \tag{3}$$

for the same field size.

2.37. *Secondary protective barriers.* The rules given above for scattered radiation and for leakage radiation may be used to compute the secondary-protective-barrier thickness for each of the two separate effects. If the barrier thicknesses so computed separately are nearly equal (that is, differ by less than 3 HVL), then 1 HVL should be added to the larger single-barrier thickness to obtain the required total.[6] But if one of the thicknesses is more than 3 HVL greater than the other, the thicker one alone is adequate.[7]

[6] Each of the two effects thus produce a permissible dose. Together they produce twice the permissible dose. This radiation can be reduced to the permissible level by the addition of 1 HVL.

[7] The larger thickness will permit transmission of the permissible level from one effect, plus not more than one-eighth (3 HVL) of the permissible level from the other effect. This one-eighth excess is negligible in view of other conservative approximations that are involved.

2.38. *Shielding.* If the shielding is adequate for the useful radiation, that is, if it is a primary protective barrier, it is more than adequate for leakage and scattered radiation. It should be determined, however, that radiation scattered around the primary protective barrier does not cause a radiation hazard.

For reasons of economy, barriers usually should be placed as near to the source as possible. The barrier thickness is not reduced by this procedure but the area and therefore the volume are reduced; the barrier weight is approximately proportional to the square of the distance between the source and the barrier.

Concrete, marble, and similar materials generally provide the most economical barrier but lead may be required where the space is limited or where it is desirable to reduce the weight.

Lead barriers shall be mounted in such a manner that they will not sag or cold-flow because of their own weight. They shall be protected against mechanical damage.

Surfaces of lead sheets at joints in the barrier should be in contact with a lap of at least ½ in. or twice the thickness of the sheets, whichever is the greater.

Joints between different kinds of protective materials shall be so designed that the overall protection of the barrier is not impaired (see figs. 1 and 2).

Windows, window frames, doors, and door frames shall have the same lead equivalent as that required of the adjacent wall. Special attention should be given to providing

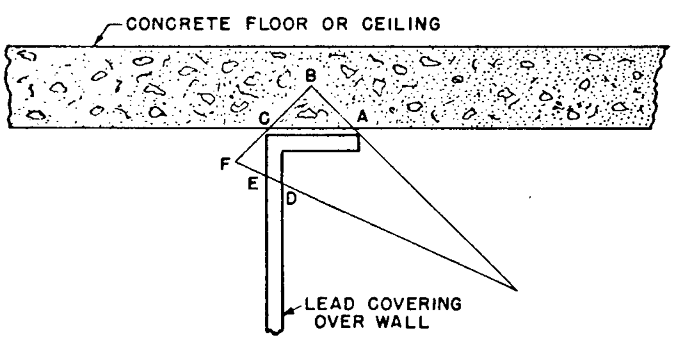

FIGURE 1. *Example of a wall joint.*

The sum of radiations through all paths ABCF and DEF to the point F shall be not more than the maximum permissible exposure. The framework supporting the lead wall is here considered to be of relatively X-ray transparent material.

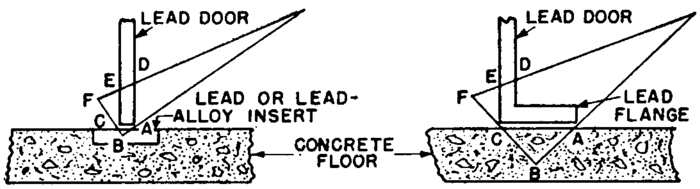

FIGURE 2. *Example of door baffle.*

The sum of radiations through all paths ABCF and DEF to the point F shall not be more than the maximum permissible exposure. The supporting structure for the lead door is here considered to be a framework of relatively X-ray transparent material.

overlap of the shielding of the door frame and the shielding of the door. See also section 5.3 Room Shielding Design for Teletherapy.

Louvers and holes in barriers for pipes, conduits, service boxes, and air ducts shall, where necessary, have baffles to insure that the overall protection afforded by the barrier is not impaired. It is advisable to locate such holes outside of the range of possible orientations of the useful beam.

3. Equipment and Facilities for Handling, Storage, and Transportation

The equipment and facilities discussed in this section refer only to sources of intermediate range, from a few millicuries to a few curies.

3.1. Handling Equipment

Radiation hazards can be significantly reduced by the proper use of suitable facilities. The extent of the facilities will depend upon the amount and type of materials used and the frequency of their use. These facilities shall be designed to permit the necessary operations to be carried out expeditiously at considerable distance from the source, and, whenever advantageous and practicable, behind protective barriers. Distance, time, and shielding should be properly adjusted with respect to the influence of one upon the others. The effects of *distance, time*, and *barriers* are discussed in section 2.

Sources should never be touched with the hands, and there should always be as much distance as practical between sources and the operator. Facilities suitable for safe handling shall be provided wherever sources are employed.

3.11. *Forceps.* Forceps for handling sources or devices incorporating sources should have the following general characteristics:

(a) They should be as long as practicable and should grip the source or applicator firmly with a minimum of force exerted by the fingers.

(b) Forceps used to lift easily damaged sources should have a "spring tip" adjusted to prevent excessive pressure. "Cross-action" forceps are desirable for some delicate manipulations.

(c) The jaws should be so notched, grooved, or otherwise formed as to fit the sources or devices to be handled.

(d) The forceps should be light in weight to permit rapid and accurate manipulation.

(e) They should be provided with hand shields of sufficient thickness to absorb essentially all primary beta rays if present.

3.12. *L-block.* The preparation and dismantling of applicators incorporating sources or similar operations, should be carried out behind a protective L-block or similar barrier of such size and thickness as will adequately shield the operator. The barrier should have the following general characteristics (see fig. 3):

(a) If the source capsule permits the escape of beta radiation, the top should be provided with an inclined high-density transparent "visor," or an alternate arrangement for viewing.

(b) The side next to the operator should have a protective pad to keep his body at least 30 cm from the point where the source is handled, or the block should be so placed on

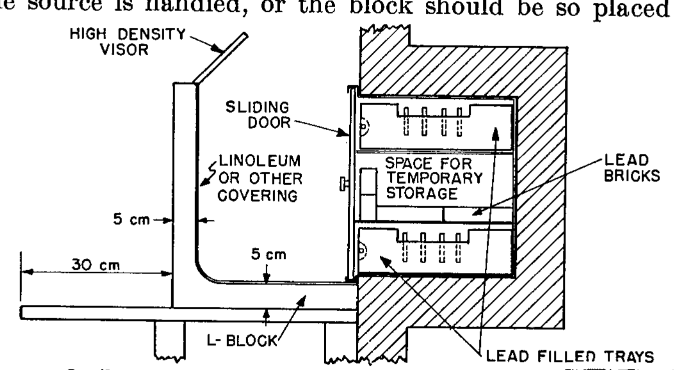

FIGURE 3. *Suggested arrangement of preparation bench with L-block and source storage enclosure recessed in wall.*

the working table as to accomplish the same result without such pad.

(c) The inside corner of the barrier should preferably be curved.

(d) For the usual barrier having a minimum lead equivalent of 5 cm, the following weekly millicurie-hours *at a minimum distance of 30 cm* are permissible: radium, 160 mc-hr; cobalt-60, 100 mc-hr; cesium-137, 360 mc-hr.

Note: The average weekly permissible exposure of 1.5 r to the unshielded hands determines the above limits. The weekly exposure to the parts of the body shielded by the barrier will then be less than 100 mr.

(e) A lead-lined "well" or its equivalent should be provided near the L-block, so that the required radioactive sources can be held therein as long as practicable during the preparation of an applicator.

3.13. *Clamping devices.* Vises, chucks, or similar arrangements should be provided at the protective barrier to facilitate handling of devices; preferably, these devices should be operated by foot pedal or by handle removed as far as practicable from the inside of the barrier. Their design and use should minimize the possibility of damaging the sources through excessive clamping pressure. This can be prevented by means of a spring-loaded ratchet or slipping-clutch mechanism.

3.14. *Threading devices.* A suitable device should be provided for threading needles or tubes expeditiously, with the fingers protected as much as possible by distance and barriers.

3.15. *Magnetic handling devices.* This method is applicable only if the sources are magnetic, i.e., either the radioactive material itself is magnetic, as cobalt-60, or the encapsulating material of the source is magnetic. The residual magnetism of these sources should not be much higher than that of soft iron, or else it may become difficult to perform the necessary operations rapidly and accurately. If the sources become permanently magnetized to such a degree that they cling together or to any magnetic material with which they come in contact, their handling, cleaning, and storage may become difficult.

3.16. *Pneumatic devices.* Vacuum may be employed to hold sources. Also, if a controlled and definitely limited impelling pressure is employed to drive sources over a short distance, certain storage and handling operations may be performed to advantage and without undue hazard, provided that the sources contain no radioactive powder or liquid and are not subject to dusting or corrosion.

The handling normally done by means of forceps may be performed to advantage by means of properly designed "hand-guns" with pistol-type grip and trigger operating on suction, provided that the construction and operation of the "gun" is such as to insure that the sources will not be damaged.

3.17. *Electromechanical devices.* Servomechanisms may be used to advantage for the selection and distribution of individual sources. Rotating storage containers have been constructed that permit selection and release of sources by remote control.

3.2. Storage Facilities

When not in use or in transit, sources and applicators incorporating sources shall be kept in a protective enclosure of such material and wall thickness as may be necessary to insure that no person is subjected to more than the applicable maximum permissible dose. This enclosure shall be provided with means to prevent unauthorized access to the source. The shielding requirements may be determined from the curves of appendix B and equations of section 2.3.

Consideration should be given to the need for ventilation of rooms used for radium storage facilities.

The protective enclosure may be advantageously located near the preparation workbench to reduce the exposure of personnel during transfers of sources.

The protective enclosure should be constructed in such a way as to minimize, as much as possible, the exposure of personnel in the handling of the sources. Important factors to consider are: (a) distribution of the sources, (b) shielding of subdivided amounts, and (c) time required by personnel to remove sources from the enclosure and return them to it.

Consideration should be given to the scattered radiation. It is not sufficient to place large sources behind a barrier, no matter how thick, if the radiation scattered around it presents a hazard. Where a large number of sources are stored, a lead-lined safe with lead-filled trays may be used to advantage. This permits the individual sources to be stored in holes in the lead of the trays.

Separate compartments should be provided for different types of sources.

Each compartment should be marked so as to permit immediate and certain identification of its contents from the outside. It is highly desirable that tubes, cells, needles, etc., be readily identifiable from a considerable distance as to their type and activity. When sizes and shapes are not adequate, other means should be employed.

The shielding provided by the individual compartments and the enclosures as a whole should be such that a person standing in front of the enclosure, in the performance of his duties, receives in that time only a small fraction of the permissible dose.

3.3. Transportation Facilities

3.31. *Transport containers*. Transportation of radioactive sources shall be done in such a manner that the exposure to any individual does not exceed the maximum permissible dose (see table 1, appendix A). Account should be taken of the actual transport time and of other possible exposures to radiation. Protection should be provided during transportation by distance and/or by shielded containers. Containers should have the following characteristics:

(a) In general, lead is the most practical shielding material for carriers. Table 8 (appendix B) gives the required thickness for various conditions. Table 7 gives the distance for unshielded sources.

(b) Loading and unloading should be possible with minimum exposure.

(c) Long handles on hand-carried containers may reduce the requirements for shielding. The design of the container should be such as to encourage the use of handles.

(d) For the transfer of large sources, a shielded container with wheels may be required to permit the use of heavier shielding and to afford greater distance between source and courier.

(e) Containers should be suitably labeled.

(f) The lid of the container should be securely fastened to prevent spillage of sources during transport.

3.32. *Special requirements for transportation by private vehicle*.[8] During transportation of radioactive sources by private vehicle (such as by physicians in practice), the source should be in a transport container offering adequate shielding to all occupants of the car.

The container should be located as remotely as practicable from occupants. It should be suitably marked with the name

[8] An opinion of the Bureau of Motor Carriers of the Interstate Commerce Commission indicates that a "physician, in transporting in his personal car instruments and medicines usually carried by such persons in pursuing their practice, including sources of radium used for treatment, would not be a private carrier of property under the Interstate Commerce Act. That being the case, the transportation of radium under the circumstances described * * * would not be subject to the explosives and dangerous articles regulations." Private communication from the Director, Bureau of Motor Carriers (11-10-52).

Tunnel and bridge authorities may regulate or prohibit the transshipment of dangerous material through vehicular tunnels and over major bridges.

and address of the owner, a notice that the contents may be dangerous if removed, and that the owner should be notified if the container is found.

If it is necessary to leave radioactive materials in an unattended vehicle, the container shall be locked in the vehicle, preferably in the luggage compartment.

Any loss or theft of radioactive material that may constitute a potential public hazard should be reported immediately to the appropriate authorities.

3.33. *Special requirements for public transport containers.* The public transportation of radioactive materials is subject to federal, state, and local regulations.

Those responsible for the shipment of sources should be familiar with the current pertinent regulations governing transport of radioactive materials including those of the Interstate Commerce Commission, Post Office Department, and Civil Aeronautics Board (see appendix E).

4. Medical Applications [9]—Interstitial, Intracavitary, and Superficial

In the medical applications of radioactive sources, there are five operational stages during which radiation hazards may exist:

(a) Transfer of sources from storage and preparation for use on patients.

(b) Transfer from preparation bench and application to patient.

(c) Irradiation of patient.

(d) Removal of sources from patient and transfer to preparation bench.

(e) Removal of sources from applicators, cleaning, and transfer from preparation bench to storage space.

Each of these stages and each type of source present peculiar problems. These will be considered individually.

4.1. Transfer of Sources from Storage and Preparation for Use

There is an unavoidable minimum exposure associated with the handling of radioactive sources. However, presuming that adequate facilities are provided, the dose for a specific procedure depends largely on the skill of the operator. The beginner should, therefore, be carefully trained with dummy applicators until a high degree of competence has been attained.

[9] The recommendations of this section also apply to veterinary medical uses.

These general precautions should be noted:

(a) Excessive use of overlong, too heavy, or otherwise cumbersome instruments will frequently increase the time of the operation to the point where the total exposure exceeds that obtainable with less physical protection and correspondingly less time.

(b) Lead rubber gloves are particularly objectionable because they provide insignificant protection and handicap the operator.

(c) Care should be taken not to let the worker dispense with protection simply because working without it seems to be the "easy" way. With training, great dexterity can be attained while still taking advantage of optimum physical protection.

(d) All applicators should be carefully designed for ease of handling. Needle eyes should be large enough for easy threading. Thread ends subject to fraying should be prepared with beeswax or plastic. Screw threads should be carefully cut and of optimum size and pitch to allow fast, jam-proof operation. Appropriate tools should be provided for the manipulation of screw caps and plugs, without the necessity of holding either the applicator or the cap or plug in the hands. All cavities in applicators into which sources are to be placed should be so designed that removal of the source, even when stuck by the accidental entrance of coagulable body fluids, can be accomplished easily and safely.

(e) All steps possible in the preparation and assembly of an applicator should be carried out before the insertion of the source.

(f) When multiple needles and capsules of the same appearance but of different strengths are used, they should be identified and marked at the time of loading. Identification by the use of small numbered tags, the numbers being recorded at the time of loading, at the time of insertion, and upon removal and unloading reduces the probability of mixing of the sources.

(g) Radium, cesium, or other powdered sources should not be heat sterilized. As these containers age, there may be considerable accumulation of gas and water vapor, the expansion of which can easily rupture thin-walled cells. Old sources that have been heat sterilized should be tested for leakage (see sec. 7.6).

(h) Attention should be paid to the possible deleterious effect of some chemical sterilizers.

(i) Areas used for preparing radioactive applicators should be monitored both for exposure to workers and for contamination from faulty containers. Radium usage, of course, demands particular attention to the presence of alpha-emitting contaminants (see sec. 9).

4.2. Application of Sources to the Patient

4.21. Only after a period of training should personnel be allowed to do this work without supervision. No persons should be engaged in this work unless they are familiar with the hazards involved and the techniques of minimizing them.

4.22. All practicable physical protection should be given. Protective barriers may be mounted on small wheeled carts and provided with sterile drapes. The barriers should be so designed as to give protection in all directions where nearby persons are usually stationed during radiotherapeutic procedures. Frequently, little or none of this is practicable during some part of the procedure. In that case, distance and speed are to be stressed.

4.23. *Physicians should neither order nor permit nurses or other persons to pick up sources with their hands.* Proper handling instruments shall be provided and their use strictly enforced.

4.3. Precautions While Source Is In or On the Patient

4.31. The bed, cubicle, or room of the hospital patient [10] should be marked with a tag or sign indicating the presence of radioactive materials. If the curiage of the sources is so large that occupancy of surrounding areas should be restricted, a special tag should indicate the safe occupancy time at appropriate distances. The patient's chart should indicate what radioactive substance is being used, the number and nature of the sources, the total amount of material, the time and date of application and anticipated removal, and any remarks that would enable the source custodian to retrieve sources.

4.32. The extent to which the patient with radioactive material must be segregated depends upon the type of source and the total curiage, its location on the patient, how long it is to be on him, how long his neighbors stay near him per week, and to what other exposure those neighbors (patients or nurses) are subject. (See table 7, appendix B.)

4.33. Patients with removable sources in or upon their bodies should not be permitted to leave the hospital or clinic.

4.34. When persons having short-lived solid sources which are not removable from their bodies are allowed to leave the

[10] This would also apply to the pen of domestic animals.

hospital, the precautions neccessary to prevent other persons from receiving more than a permissible dose of radiation will depend upon the nature of the isotope and the quantity present. Table 7 gives the appropriate distance-time-intensity data from which specific protection instructions may be derived.

Such patients should always carry a wristband or similar suitable identification on their persons which gives the necessary information concerning the presence of a radioisotope, the quantity, the date of implantation, and the name and address of the physician to be called in case of emergency.

4.4. Removal of Sources from Patient and Transfer to Preparation Bench

4.41. The same safety precautions observed at time of insertion shall be observed at time of removal, and all sources shall be accounted for.

4.42. Precautions shall be taken during cleaning of applicators to prevent damage or loss of sources.

4.5. Accountability

In every hospital or clinic stocking sources there shall be a custodian of sources. This custodian or his deputy shall keep a permanent record of the issue and return of all sources. This record should include:

(a) The source order with its date, and date received.

(b) The name of the patient and hospital or department, and physician who issued the order.

(c) Source issued: stating type and identification of appliance, number of sources and total curiage, person to whom issued, signature of individual receiving the material, date and time of issue.

(d) Date of expected return, date of return of source, signature of individual certifying complete return.

The source custodian shall take periodic inventories of all sources.

5. Medical Applications—Teletherapy

5.1. Radioisotopes as Sources for Teletherapy Apparatus

5.11. *Possible sources.* Table 4 (appendix B) includes radionuclides of interest for teletherapy sources. Most teletherapy sources can be expected to deliver between 1 and 50 r/min at a distance of 1 m. Such sources will have exposure rates of many kiloroentgens per minute close to their surfaces and when not in their housings must be handled with remotely controlled instruments at great distances or behind thick barriers. Apparatus containing such sources shall be constructed not only to be practically foolproof in operation but also so that it is very unlikely that any accident will leave the source unshielded.

5.12. *Physical form of the source.* Some of the isotopes shown in table 4 (appendix B) can exist as solid metals and can be cast, machined, or pressed before irradiation. The metallic state is usually the most stable and easily handled, and therefore the preferable form for a source. Solid sources are likely to consist of multiple wafers, pellets, or cylinders, which must be fitted into a container.

Some sources can exist only as powdered salts. Before irradiation, such salts can be mixed with metallic powder (for example, aluminum), and pressed into metallic disks to avoid the hazards associated with powdered sources. Some materials, such as cesium sulfate, have too low a specific activity to be mixed with a metallic powder but can be pressed to reasonably high density within their containers to reduce the hazards of the powdered form. Some isotopes could conceivably be used in a loose powdered form or in a liquid form.

The use of loose powders and the possible corrosion of the solid metals, pressed metallic disks, and pressed powders, can cause a dust problem; the containers must be designed to prevent the release of radioactive dusts.

5.13. *Preparation of source.* Certain sources (e.g., cobalt-60 and iridium-192) can be prepared as metals or metallic alloys of high purity. Radioactive isotopes of certain elements, such as cesium, europium, and radium, are not readily available in pure metallic form. Usually the oxides, chlorides, or sulfates are used. It is desirable to use an element or compound that yields the highest volume specific activity, but such characteristics as deliquescence, decomposition, and gas production in a high gamma-radiation flux shall be taken into consideration.

5.14. *Source capsules.* Sources used in teletherapy shall be sealed in capsules which are not easily breakable. Quantities of a few curies can be sealed in airtight source holders. Sources larger than a few curies have very high internal gamma intensities and are subject to decomposition of salts and minor contaminants, appreciable heat generation, and the potential production of gases, with a buildup of pressure within the source container. Such sources should be sealed in a welded container which is contained in a second welded container.

A standard source capsule for teletherapy used internationally is shown in figure 4. The standardized external dimensions of the capsule have proven to be a convenience to the source manufacturer, the teletherapy machine manufacturer, and the person having occasion to replace a source. (Appendix C contains a more detailed discussion of source capsules.)

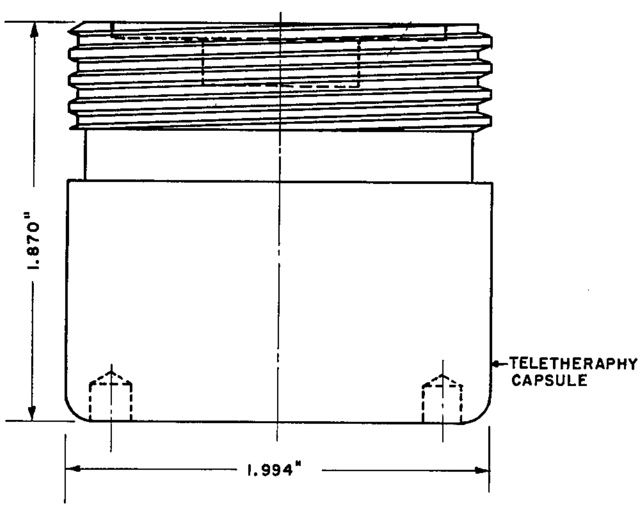

FIGURE 4. *Standard source capsule for high-curiage teletherapy.*

5.15. *Testing of sources by the manufacturer.* After the source is loaded into the inner welded container, the container shall be scrubbed clean of contaminating radioactivity. It shall not be placed into the second container until a reasonable test reveals no significant contamination. A recommended test is to scrub the dry container with a dry filter-paper sponge and to count the activity on the paper under standardized geometry. After welding of the second container, the container should again be checked for contamination.

Upon completion of the source assembly, the assembly shall be checked by the manufacturer for contamination.

5.16. *Testing of sealed teletherapy source containers during use.* All sealed teletherapy source containers shall be tested periodically for leakage by wiping accessible surfaces of the source housing. If significant radioactivity is found, action should be taken to prevent any extensive spread of contamination, and the source supplier and the Atomic Energy Commission or other appropriate regulatory agency should be contacted for specific instructions. Various test techniques are described in section 7.6.

5.17. *Replacement of teletherapy sources.* Persons replacing used teletherapy sources shall conduct a thorough radiation survey of the source assembly housing upon removal of the used source. Any removable contamination found in the housing shall be removed prior to insertion of the new source. Old-type lead-gasketed source holders should be discarded when the source is replaced.

Should the radiation survey of the source assembly housing reveal contamination, the used source shall not be re-used until it has been definitely determined that the source is not leaking. Such a determination may require that the source be inspected in an appropriate hot cell.

5.2. Teletherapy Apparatus [2]

5.21. *Protection requirements for the source housing.* The housing shall be so constructed that at 1 m from the source, the maximum and the average exposure rates do not exceed 10 mr/hr and 2 mr/hr, respectively, when the beam control mechanism is in the "off" position. Sufficient measurements should be made to insure that the above values are not exceeded. (An acceptable method for obtaining the average exposure at 1 m from the source is to take measurements at 8 compass points in each of 3 planes at right angles to each other 1 m from the source. This may require 18 independent measurements. Small areas of reduced protection are acceptable in evaluating the maximum exposure rate providing the average over 25 sq cm at 1 m distance does not exceed 10 mr/hr.) In the design of equipment, consideration should also be given to reducing the surface exposure rate; this is particularly important in the design of small diameter housings.

The leakage radiation measured at 1 m from the source shall not exceed 0.1 percent of the useful beam when the beam control mechanism is in the "on" position.[11] This limit, however, does not apply to source housings where the leakage radiation at 1 m is less than 1 r/hr. If the housing does not have movable diaphragms to block the useful beam in the "on" position, it may be necessary to plug the aperture with

[11] The requirements for shielding in the "on" position do not apply to apparatus used exclusively for whole-body irradiation. However, attention is called to the possible greater room-shielding requirements.

a block of lead providing protection equal to that of the adjacent wall of the housing while making this measurement. Measurement of "on" position leakage is not required on each source housing if results are available of measurements on an exact prototype. A reduction of the leakage radiation below these values may result in more economical secondary protective barriers.

5.22. *Special requirements for multiple source equipment.* In multiple source equipment, the leakage radiation from any single source, plus the contribution from all others, shall not exceed that given in section 5.21.

5.23. *Protection requirements for the collimating device.* Adjustable or removable beam-defining diaphragms shall allow transmission of not more than 5 percent of the useful-beam exposure rate. Auxiliary beam-defining devices need not meet this requirement.

5.24. *Filters.* Filters to harden the radiation are usually unnecessary in most teletherapy machines. In the case of some radionuclides where filtration of soft gamma rays is necessary, the filter should be a permanently affixed part of the housing.

5.25. *"On" position requirements.* In the "on" position, the moving part shall always come to rest with the source and the beam collimating device accurately alined. If a liquid "on-off" device is used, repeated operation of the device shall not cause a variation of more than 5 percent in exposure rate in the "on" position. If the liquid is mercury, periodic tests should be made for leakage of mercury vapors, since they are toxic [18] and also may affect the film badges used in monitoring personnel.

5.26. *Beam control.* The beam-control mechanism shall be of a positive design capable of acting in any position of the housing. In addition to an automatic closing device, the mechanism shall be so designed that it can be manually returned to the "off" position with a minimum risk of exposure. The moving parts shall be so designed that it is highly improbable that the apparatus will fail to return to the "off" position. There shall be at the housing and on the control panel a warning device that plainly indicates whether the beam is on or off. The control panel shall be provided with a timer that automatically terminates the exposure after a preset time.

5.27. *Precautions in the "on-off" beam-control mechanism.* Whatever the type of "on-off" beam control mechanism (liquid, slide, wheel, or shutter), the closing device shall be so designed as to return automatically to the "off" position in the event of any breakdown or interruption of the activating force and shall stay in the "off" position when the force goes on again until activated from the control panel.

When the door to the treatment room is opened, the beam-control mechanism shall automatically and rapidly restore the unit to the "off" position and remain there until the unit is reactivated from the control panel. As an added precaution, a warning device not usually in evidence (such as a loud alarm bell) can be provided to come into operation if the unit should fail to return to the "off" position when the door is opened. The "on-off" beam control mechanism should also be such that the beam cannot be turned on from inside the treatment room.

The equipment shall be provided with a locking device to prevent unauthorized use. Where teletherapy equipment is used also for irradiation of animals, plants, and other experimental material, operating procedures and equipment may be modified to meet the requirements of the research objectives provided that the precautions listed in section 6.3. are followed.

With each teletherapy apparatus, emergency regulations shall be in force (see sec. 5.5. and appendix D).

5.28. *Apparatus incorporating a primary beam shield.* A primary beam shield that remains fixed in its relationship to the useful beam is not considered a movable barrier. Where the relationship between the useful beam and the primary shield is not fixed, mechanical or electrical stops shall be provided to insure that the beam is oriented only toward primary barriers.

5.29. *Radiation hazards as a result of fire.* In the design of the source housing, consideration shall be given to the integrity of the lead shield in case of fire. The source capsule should be so designed as to minimize the probability of escape, in case of fire, of radioactive material therein contained.

5.3. Room Shielding Design for Teletherapy

The shielding requirements for teletherapy installations vary widely with the type of equipment, workload, use factor, and degree of occupancy of adjacent areas. Tables 5 and 6, appendix B, give the required barrier thicknesses of lead and concrete for the more common conditions. The graphs of figures 6 to 10 (appendix B), and the equations of section 2.3. permit barrier determinations for other conditions.

Equipment with a built-in shield which attenuates the primary beam to the same degree as the source housing and intercepts the useful beam at all times requires only secondary barriers in floor, ceiling, and walls, as these areas are exposed only to scattered and leakage radiation. Although they may all meet the recommendations of section 5.21., different types of equipment produce considerably different amounts of leakage radiation; the actual leakage radiation in the directions of interest should be taken into account when designing the room shielding.

There is, in general, considerable saving in shielding cost by using a radiation maze rather than a heavily shielded door for the entrance to the teletherapy room. A typical maze design is shown in figure 5. The door of the maze usually requires only 1.5 to 3 mm of lead as the radiation striking it has been scattered several times and is therefore of lower energy.

Provision shall be made to permit continuous observation of patients during irradiation. High density glass for viewing windows is now available of sufficient thickness to be used without lamination if the window is located in a

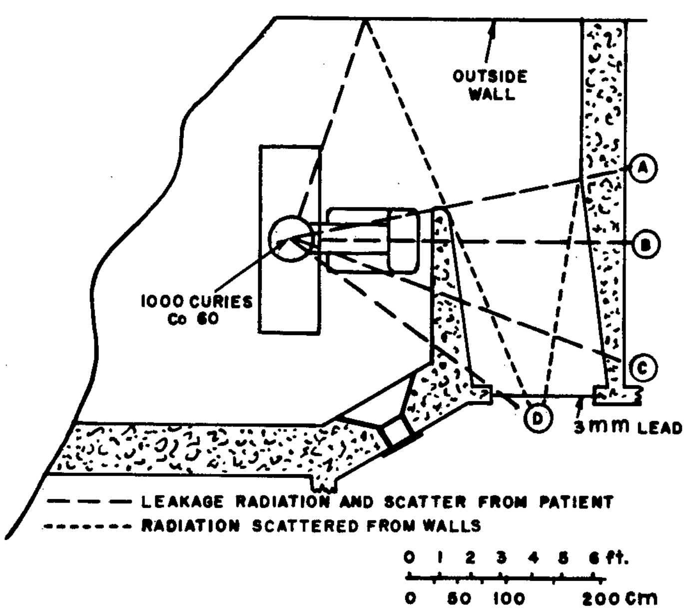

FIGURE 5. *Typical maze design for stationary kilocurie cobalt equipment.*

The barriers must be thick enough to reduce the radiation at positions A, B, C, and D to appropriate levels with due consideration to all sources of scattered and leakage radiation.

secondary barrier. A lead frame is usually required to prevent leakage around the window through the area of reduced thickness of the concrete wall. The need for a thick wall window may sometimes be avoided by the use of mirrors and a thinner (lead equivalent about 3 mm) lead glass window in the maze door. A closed circuit television system may also be used for viewing the patient.

Provision for oral communication with the patient from the control is desirable.

5.31. *General structural requirements.* Movable barriers not part of the equipment should not be depended upon except for emergency procedures. The control should be in a separate room. All access doors to the treatment room and other hazardous areas shall be provided with interlocks (section 5.27) and warning lights.

5.32. *Primary protective barriers.* Primary protective barriers shall be provided for any area that the useful beam may strike when using the largest possible diaphragm opening. These barriers should in general extend at least 1 ft beyond the useful beam for any possible orientation. The actual protection requirements will depend upon the type and rhm of the source, the weekly irradiation hours, use and occupancy factors, and type of occupancy. The barrier shall be such that no person outside the radiation room receives more than the maximum permissible dose (see table 1 (appendix A) and tables 3, 5, and 6 (appendix B)).

5.33. *Secondary protective barriers.* Secondary protective barriers shall be provided for all occupied areas exposed to leakage and scattered radiation. See tables 3, 5, and 6 (appendix B).

5.4. Operating Procedures

No person who works with ionizing radiation shall be in the treatment room during irradiation. No other person shall be there except when it is absolutely clinically necessary; at all other times, the treatment room should be occupied only for necessary and authorized purposes.

5.5. Emergency Procedures

In the event of fire in the vicinity of the teletherapy equipment, firefighters may enter the treatment room after irradiation has been terminated. There is little likelihood of radiation hazards unless the temperature of the source housing reaches the melting point of lead (621° F.). (Should the lead melt, there is the possibility of voids in the source shielding with resultant excessive stray radiation.) Water should be sprayed on the housing if there is any possibility of the temperature approaching this value. A liaison should be made with firefighters or other emergency crews whereby they will be kept up to date on the location of all sources. A mutually agreed upon marker especially designed for quick recognition by the emergency crews may be used to mark doors or vaults containing sources. The firefighters and other emergency crew members should know in advance what precautions should be taken in an emergency involving sources.

See appendix D for an example of emergency procedures to be followed in case of beam control failure.

6. Nonmedical Applications

6.1. General

6.11. This section deals with all nonmedical applications within the scope of this Handbook. Specific consideration is given here to the uses of sources in instrument calibration, research, and civil defense exercises.

6.12. In the event that a situation beyond the reasonable contemplation of these recommendations is believed to exist, any deviation from these recommendations shall be allowed only upon authorization by the radiation protection officer or qualified expert after a thorough survey of the conditions.

6.13. A label stating type and amount of activity shall be attached to each source container. Lettering shall be legible from a safe distance.[12]

6.14. Whenever possible the source capsule itself should have a mark identifying the radionuclide engraved or etched on it.

6.2. Calibration Sources

6.21. Calibration sources having exposure rates less than 1 mr/hr at 5 cm from the surface of the source do not singly represent radiation hazards. However, precautions against escape of free radioactive materials from the source shall apply. Sources that singly do not represent radiation hazards may produce such a hazard when more than one are located in the same vicinity as in the case of bulk storage.

6.22. Low-level sources intended for hand manipulation during the calibration of monitoring instruments shall have an exposure rate of less than 1 mr/hr at 5 cm from the surface of the source.

[12] For exempt quantities and methods of marking, see sections 20.203(f) (1) and (4), AEC regulation on Standards of Protection Against Radiation, Title 10, Code of Federal Regulations, Part 20. See reference [21].

6.23. Calibration sources permanently mounted within an instrument shall not produce more than 10 mr/hr at any surface of the instrument readily accessible during either normal operation or the performance of routine maintenance. The presence of such sources shall be clearly indicated by a suitable permanent legend (see footnote 12) on the face of the instrument stating the radionuclide and its curiage. The source shall be readily distinguishable upon dismantling the instrument.

6.24. Remote-handling equipment shall be used with sources having an exposure rate of more than 1 rhm. Movement of sources from shielded position to calibration position should be accomplished by mechanical linkage or other remote-control methods. However, in the case of radium and other powder sources, only those methods of transfer should be used that do not subject the source to repeated shocks or vibration, and that provide positive automatic safeguards against the possibility of damage to the source and spread of contamination due to malfunction of the system. An indicator shall be provided to show when the source is in calibration position. Any area where the exposure of a person may exceed 100 mr in an hour shall be made inaccessible unless the area is under surveillance.

6.3. Research Applications

6.31. Sources shall be subject to the provisions of sections 6.1. and 6.2. except as otherwise permitted by the radiation protection officer. Any such modifications shall not increase the exposure of persons beyond the permissible level.

6.32. It shall not be considered sufficient to calculate exposure rates for multicurie sources from consideration only of the amount of activity present. For such sources measurements should be made of the radiation levels. Consideration must be given both to primary and scattered radiation.

6.33. Teletherapy apparatus used for research shall be subject to the same design criteria and operational precautions as those recommended in section 5 for medical teletherapy apparatus except that considerations given to the protection of the patient against accidental overexposure shall not apply where animals, plants, and other experimental materials are being irradiated. Precautions, however, should be taken by means of entrance interlocks, locks, or surveillance by the operator, to prevent persons from entering the irradiation room while the beam is in the "on" position.

6.4. Civil Defense

6.41. Civil defense uses present two special problems in field operations: (1) extremely rough usage, and (2) possible use by untrained personnel.

6.42. Sources should be encapsulated in containers especially designed for protection against rupture when subjected to rough usage. Glass containers shall not be used. The curiage of any source should be the minimum required for the purpose.

6.43. Markings should be provided and should give, in addition to type and amount of activity, information concerning radiation hazards and dangers attendant upon rupture of the source containers.

6.44. A day-by-day inventory of all sources should be made during civil defense field exercises. The source custodian should be required to keep a written record of location to minimize the possibility of losses and associated hazards.

7. Radiation Protection Surveys and Personnel Monitoring

7.1. Protection Surveys

7.11. All new installations, and existing installations not previously surveyed, shall have a protection survey made by, or under the direction of a qualified expert. A resurvey shall be made after every change which might increase the radiation hazard. In evaluating the results of the survey, account should be taken of actual operating conditions, including workload, use factor, and occupancy. Radiation surveys are not required of installations using only low activity sources exempted by regulatory authorities.

7.12. If safe use of an installation depends upon mechanical or electrical restrictions of the orientation of the gamma-ray beam and/or on other limitations, an inspection shall be made to see that these restrictions are actually imposed. If there is a possibility of a fault developing through cold flow in metallic shielding or through wear, the survey should be repeated at appropriate intervals.

7.13. All interlocks shall be tested to make certain that they are operating properly. An inspection shall be made to determine that any warning signals are properly located and functioning.

7.14. The exposure rate shall be determined for any area where there is any reasonable probability that the occupants may receive more than the maximum permissible dose (see table 1, appendix A).

7.2. Storage Containers

7.21. The survey of storage facilities should be made with all the usual sources in the storage container. The radiation levels should be determined in all nearby occupied areas and limitations indicated, if necessary, with warning signs.

7.3. Teletherapy

7.31. No teletherapy installation should be used for the treatment of patients until its safety has been established by a protection survey. The survey shall include measurements made with the beam in the "off" position to determine that the equipment complies with the requirements of a protective source housing (see sec. 5.21).

7.32. Measurements shall also be made with the beam on to determine the exposure rate in all occupied areas near the radiation room. A patient or phantom should be in place when scattered radiation is measured. Such measurements should be for typical useful-beam directions to determine the exposure rates under actual conditions of operation (see sec. 7.11). The survey shall include those treatment situations likely to cause the highest dose to operating personnel and other persons in nearby areas; a resurvey should be made when new treatment techniques are contemplated which might increase the radiation hazards.

7.33. If safe use of the installation depends on mechanical restrictions of the orientation of the teletherapy beam or on the presence of a primary beam shield, then an inspection shall be made to see that these restrictions are actually imposed.

7.4. Report of Radiation Protection Survey

7.41. The expert shall report his findings in writing to the person or agency requesting the survey and to the person in charge of the installation.

7.42. Exposure rates at all occupied areas shall be indicated in milliroentgens per hour. If, at any of the indicated positions, any person is likely to be exposed to more than the maximum permissible dose (table 1, appendix A), then recommendations of changes to eliminate the radiation hazard shall be made, with due regard to actual operating conditions, including workload, use factor, and occupancy. The report shall indicate also whether or not the installation complies with pertinent codes.

7.43. Recommendations for corrective measures may include changes in operating techniques, equipment, mechanical restrictions of the beam direction, barriers, etc.

7.44. The report should indicate whether or not a further survey is necessary after corrections have been made.

7.45. Recommendations shall include any necessary changes in the personnel monitoring techniques.

7.46. Copies of each report shall be kept on file by the expert and by the person in charge of the installation. Copies of pertinent sections dealing with limitations of occupancy, operating techniques, and/or workload, should be posted near the control panel.

7.5. Periodic Inspections

7.51. All interlocks, on-off beam-control mechanisms, safety and warning devices on teletherapy installations should be checked and appropriately serviced at regular intervals (at least once in 6 months).

7.52. The location of radioactive sources shall be checked at regular intervals (at least once in 6 months).

7.53. Operating procedures and work habits of employees should be reviewed for changes in workload, occupancy, or radiation safety practices.

7.54. Records of dates, findings, and changes shall be kept on file.

7.6. Radioactive Source Leakage and Contamination

7.61. All radioactive sources shall be tested for contamination prior to initial use. All sources, except solid corrosion resistant metals or alloys should be tested for leakage at least every 6 months. If there is reason to suspect that a source might have been damaged, it shall be tested for leakage before further use.

7.62. A satisfactory method of leak testing is to line the source storage container with absorbent material (such as filter paper, blotter paper, felt, or velvet) and to measure the lining material for contamination. The source should fit snugly in its storage well so that it is wiped by the absorbent material when being inserted and removed. Counting may be done with the lining material in place if the instrument will fit into the storage well. The wiping technique and the instrument used for counting should be sufficiently sensitive to detect 0.005 microcuries of alpha, 0.05 microcuries of beta or 0.1 mr/hr of gamma contamination contained on the source. Wiping with absorbent material, such as a cotton-tipped swab, is also a satisfactory method for leak testing most sources.

For high activity sources such as those used in teletherapy where the wiping of the source itself might be hazardous, the test for leakage should be made by wiping accessible surfaces of the housing port or collimator while the source is in the "off" position and measuring these wipes for transferred contamination.

7.63. Whenever any significant removable contamination is detected, the source shall immediately be removed from service and sealed in a separate container to prevent the spread of contamination. As soon as practicable, it should be returned to the supplier, or sent to some other qualified person, for repair or disposal. All equipment which has been in contact with the source shall be checked for contamination and decontaminated if necessary. (See section IV, NBS Handbook 48 [12].)

7.7. Personnel Monitoring

7.71. Personnel monitoring shall be required for each individual for whom there is a reasonable probability of receiving a yearly exposure dose exceeding 1¼ r. This limit does not include medical exposures.

7.72. Personnel monitoring shall be required for all teletherapy personnel. It shall also be required for individuals working in controlled areas where frequent change in the number, variety, curiage, and location of sources and other source containers is likely.

7.73. It is recommended that a qualified expert be consulted on the establishment of the monitoring system. Records shall be kept of all personnel monitoring results.

7.74. Monitoring may be done with film badges, pocket chambers, pocket dosimeters, or similar devices. (See NBS Handbook 57 [14] for details of film-badge monitoring.)

8. Working Conditions

8.1. General

8.11. Before a person is allowed to handle radioactive sources he shall be informed of the hazards involved and how to guard against them. Such an employee should be required to read the sections of this Handbook pertaining to his work and any special local safety rules.

8.2. Radiation Protection Officer

8.21. The radiation protection officer should be responsible to the user for advising on the establishment of satisfactory working conditions according to current standards, including those recommended in this Handbook and for compliance with all pertinent federal, state, and local regulations.

8.22. The specific duties of the radiation protection officer or his deputy should include:

(a) The instruction of new personnel in safe working practices and in the nature of injuries resulting from over-exposure to radiation.

(b) Establishing and maintaining operational procedures so that the radiation exposure of each worker is kept as far below the maximum permissible as is practicable.

(c) Assuring that under normal conditions no one except patients receives more than the maximum permissible dose per week.

(d) Investigating each case of excessive or abnormal exposure to determine the cause and taking steps to prevent its recurrence.

(e) Assuring that personnel monitoring devices are used where indicated and that records are kept of the results of such monitoring.

(f) Assuring that adequate records are kept of all sources indicating their locations or the name of the person to whom they have been assigned.

(g) Conducting periodic radiation surveys where indicated (see sec. 7) and keeping records of such surveys, including descriptions of corrective measures.

(h) Assuring that all shields, containers, and handling equipment are maintained in satisfactory condition.

(i) Assuring the posting of any region that is readily accessible and cannot be continuously occupied without exceeding the maximum permissible dose, and warning all concerned that this is a potentially hazardous area. This specifically applies to regions where sources are stored or handled and areas where patients are being treated.

(j) Assuring the performance of periodic leak test of sealed sources.

8.3. Physical Examination [13]

8.31. Preemployment medical history (including previous radiation exposure) and physical examination (including

[13] If the shielding facilities and working conditions recommended in this Handbook are maintained, radiation exposures should be well below those that are expected to produce any measurable physiological effect.

complete blood count and urinalysis) are advisable to determine preexisting conditions and to establish baseline values for the individual.

8.32. Whenever it is known or suspected that a person has received exposure in excess of the maximum permissible dose, a blood count should be done immediately so as to be prepared to detect any later resultant changes. (It is doubtful that any significant change in the blood count can be detected if the single exposure dose to the whole body is less than 25 r.)

8.33. Records should be kept of reports of physical examinations and blood counts.

8.4. Vacations

8.41. Vacations should not be considered a substitute for adequate protection against exposure to radiation.

9. Accidents Entailing Radiation Hazards [14]

9.1. Introduction

9.11. The escape of radioactive materials from sealed sources may occur. Such incidents are likely to create health hazards, and the cost of decontamination may be extremely high. The causes of such incidents are often obscure. Constant vigilance is required to guard against spillage of radioactive materials and also against loss of the sources. Appropriate emergency procedures should be established for possible accidents.

9.12. The hazards resulting from contamination of humans and the entry of radioactive substances into the body vary greatly depending on their physical and chemical properties and forms. Because the metabolism of these elements in humans is often not well understood, rather detailed study procedures are described in order to provide further helpful information for any incident that may occur as well as to protect exposed individuals.

9.2. Spillage

9.21. If there is reason to suspect that a disruption of a sealed source has occurred, any or all of the following emergency measures may be appropriate:

(a) No immediate attempt shall be made to clean up the spill.

(b) All windows shall be closed, fans and air-conditioners shall be shut off, and everyone shall leave the room.

[14] See also references [3], [5], [11], and [17].

(c) All doors shall be closed and locked.

(d) If powdered or gaseous sources are involved, the door and all other openings leading into the room shall be sealed with wide masking tape or adhesive tape and heavy wrapping paper.

(e) Every person who might have been contaminated shall be tested and immediate steps taken to remove any radioactive contamination.

(f) Entrance to the contaminated area shall be prohibited except to authorized persons requiring access in the performance of their special duties.

(g) A qualified expert should be called in and his advice followed.

(h) An instrument capable of indicating alpha radiation is useful in locating radium contamination.

(i). Special problems associated with the spillage of liquid sources are covered in NBS Handbook 48 [12].

9.22. Under no circumstances shall any untrained person attempt to examine or clean up any spilled radioactive material. (The cleanup technique should be planned with the same care as is used in quantitative chemical analysis or in bacteriological handling of extremely virulent organisms.) Fans or ventilating apparatus should not be turned on in an attempt to blow away the radioactive material or its decay products. Such a maneuver will only disseminate the radioactive material throughout the area. If the radioactive material is blown out of a building, air currents may carry the finely divided material into nearby windows or air-intake ducts. Proper precautions taken immediately will protect human life and minimize financial losses.

9.3. Emergency Care for Possibly Contaminated Persons

(Procedure to be followed if qualified expert is not available)

9.31. All persons suspected of having been contaminated should be surveyed. If this cannot be done immediately, such persons should not be permitted to leave beyond what will be considered a safe distance from the contaminated area.

9.32. If no monitoring instrument is available, all possibly exposed persons should be regarded as contaminated. Wipes from various parts of the bodies of these persons and their clothing should be made with some type of disposable tissue, filter paper, or blotting paper, and the samples placed in separate labeled envelopes for future study.

9.33. Contaminated clothing should be removed carefully and placed in some type of disposable container or bag.

If this is not available, clothing should be put on sheets of paper to prevent contamination of floor and furniture. The clothing and paper can be monitored later to determine the presence of contamination and the need for decontamination or disposal.

9.34. If necessary, contaminated persons should be taken to a shower area for bathing.

9.35. Bathing should be done under showers and commercially available detergents and soaps can be used. Several separate washings should be performed. Highly alkaline soaps, abrasives, organic solvents, or cleaners that tend to increase permeability of the skin should not be used. Special emphasis should be given to cleaning of fingernails, toenails, nostrils, scalp, ears, and body folds.

9.36. Scrub brushes should be used, but care should be taken that the skin surfaces do not become abraded.

9.37. After the body is well washed, the person should be surveyed with a suitable monitoring instrument and additional smears taken with disposable tissues, cotton-tipped applicators, or filter paper. The ear canals and nostrils should be swabbed for contamination. Smear tests are especially important if alpha contamination is suspected and appropriate survey instruments are not available. Clothing known not to be contaminated should be put on.

9.38. Small cuts and other breaks in the skin surface should be sought for carefully, since absorption of radionuclides can occur by this route [3].

9.39. A physican should be called immediately to recommend and take further action. Any or all of the following steps may assist in the formulation of his recommendations:

(a) Complete medical history and physical examination with special emphasis on previous occupational history and possible exposure to radiation, and chest roentgenogram.

(b) Complete blood count, including hematocrit reading, and routine urinalysis.

(c) Quantitative collection of urine for the first 72 hr. for determination of radioactivity. Each day's specimen should be put in a separate container. These specimens may be collected in bottles containing 10 ml of dilute nitric acid (approximately 10 ml of concentrated nitric acid per liter of water) for each 24-hr. specimen. An additional 10 ml of concentrated nitric acid should be added to the specimen after the collection is complete.

(d) Feces collected for the first 72 hr. for determination of radioactivity. Each day's specimen should be put in a separate container. These can be collected in round, 1-qt. (1-liter) ice-cream containers.

(e) Breath samples for radon if the accident involves radium.

(f) Arrangement for surveys of the total body gamma radiation with a sensitive measuring device.

(g) Samples of blood within 72 hr. for determination of radioactivity.

(h) The specimens of urine, feces, and blood should be refrigerated and kept until arrangements can be made for analysis at a qualified laboratory. Proper collection and storage of these samples may be of great value to the contaminated persons and also in obtaining further data concerning the metabolism of the radionuclide involved.

9.4. Special Problems

9.41. *Radium* [17]. The chief hazard of radium is the danger of retention of long-lived alpha-emitting radionuclides in the body. The amount of retention depends in part on the salt of radium used. The insolubility of radium sulfate tends to permit less absorption in the body than is the case with the more soluble radium chloride and radium bromide.

Treatment for radium retained within the body should be carried out under the direction of a physician. A suggested method of treatment is as follows:

(a) Gastric lavage with 10-percent magnesium sulfate solution should be done as soon as possible.

(b) Daily purging with saline cathartics will tend to promote excretion of radium from the gastroenteric tract, and this type of cathartic will act as a mild stimulant to bile production. Since absorbed radium is excreted to a large degree in the bile, such therapy may be of some value. Administration of magnesium sulfate is suggested, since it will tend to precipitate soluble radium ions in the form of the insoluble sulfate.

(c) If contaminated cuts and other skin lesions cannot be adequately decontaminated, surgical excision of the area should be considered.

9.42. *Other isotopes*. Certain other radioactive radionuclides are now being used widely both in sealed containers for local irradiation therapy in millicurie quantities and also in teletherapy installations in kilocurie amounts.

(a) *Cobalt-60*. The hazard of spillage from cobalt-60 is relatively small. If Co^{60} sources are not sealed in containers or adequately plated with gold or other coating, some contamination may result from oxidation or corrosion of cobalt.

No attempt should be made to remove any protective plating of Co^{60} except by qualified laboratories.

The general procedures to be followed in the event of spillage have been described. Decontamination may be carried out by the use of various complexing agents such as the versenes used with detergents. If Co^{60} is introduced through the skin, areas of local inflammation and possibly sterile abscesses may result. The first critical organ for Co^{60} is the liver, then kidney, spleen, and pancreas. After oral ingestion in laboratory animals, elemental Co^{60} is poorly absorbed. The biological half-life in the body is 9.5 days.

(b) *Cesium-137*. This radionuclide is usually produced as powdered Cs_2SO_4 and then is utilized in a sealed container. The radiation stability of cesium-137 must be carefully evaluated, since certain cesium salts decompose with evolution of oxygen. Therefore, the hazards are similar to those of radium, except that cesium is not a bone-seeker.

Cesium-137 has a biological half-life of 140 days in the human. The first critical organ is muscle, then kidney, spleen, liver, and bone, in order. The metabolic pattern of cesium is similar to that of potassium but its retention in the body is longer.

If Cs^{137} escapes from a sealed container, decontamination may be done with aqueous solutions of detergents or dilute nitric acid.

(c) *Iridium-192*. The uses of this radionuclide are for medical therapy and industrially as a gamma source for measurement and radiography. The medical sources are usually plated with copper and made available in plastic ribbons.

The biological half-life for the whole body is 20 days. The first critical organ is kidney, then spleen and liver. There is not significant absorption from ingested metallic iridium.

(d) *Gold-198*. Small seeds are used for implantation in the same manner as are radon or iridium seeds. Except for accidental loss, no hazards need be anticipated.

(e) *Chromium-51*. Small seeds cut from pure chromium wire are used for implantation. They are found to be unusually inert chemically.

9.43. *Loss of sources*.

(a) Any loss of a source shall be reported immediately to the radiation protection officer.

(b) In case of suspected loss all linen, dressings, clothing, and equipment shall be kept within the cubicle or room of a patient until all sources are accounted for.

(c) Each institution should have available one or more portable instruments capable of detecting gamma radiation levels as low as 0.1 mr/hr. Usually instruments of the ionization-chamber type are less sensitive but more rugged than survey meters using Geiger-Mueller or scintillation counters. Geiger-Mueller survey instruments when used in fields of high radiation intensity may fail to respond and thus give inexperienced persons a false sense of security. (For further details see NBS Handbook 51 [13].)

9.5. Decontamination Procedures

(Procedure To Be Followed if a Qualified Expert Is Not Available)

The following recommendations will facilitate the cleanup of a radioactive material especially when it is in the form of a powder [5].

(a) A traffic-control program should be instituted immediately to minimize trackage.

(b) The following equipment should be assembled: respirators, coveralls, shoe covers, vacuum cleaner, and steel drums for refuse. Either inexpensive latex or plastic overshoes can be used. Ordinary brown paper bags may be used as shoe covers in an emergency.

(c) Periodic surveys with appropriate radiation detection instruments should be performed and the readings recorded on an area map.

(d) Vacuum cleaning shall be performed before wet mopping or scrubbing. By vacuum cleaning first, the contamination will be reduced significantly and less radioactive material will become lodged in the flooring. Some type of approved filter for 0.2-micron particles should be put on the exhaust opening of the vacuum cleaner. For example, water filter vacuum cleaners have been efficient. The operator should wear a suitable respirator and helmet. Central vacuum systems shall not be used.

(e) After dry vacuum cleaning, damp mopping with a detergent and chelating agent will help to remove radioactive contamination.

(f) Appropriate smear checks shall be made on the cleaned surfaces in order to determine effectiveness of the cleanup campaign. Large paper towel smears of shoe covers may be checked in a low background area to give indications of progress.

9.6. Disposal of Radioactive Materials

9.61. It is not practicable in this Handbook to provide detailed information concerning the disposal of radioactive materials. Such information can be obtained from the supplier, from licensed commercial waste disposal services, or from the U.S. Atomic Energy Commission [21].

10. References

[1] C. B. Braestrup and H. O. Wyckoff, Radiation protection (Charles C. Thomas, Publ., Springfield, Ill., 1958).
[2] M. Brucer, Teletherapy design problems, Radiology **62,** 91 (1954).
[3] A. J. Finkel and E. A. Hathaway, Medical care of wounds contaminated with radioactive materials. J. Am. Med. Assoc. **161,** 121 (1956).
[4] F. S. Frantz Jr., and H. O. Wyckoff, Attenuation of scattered cesium-137 gamma rays, Radiology **73,** 263 (1959).
[5] R. G. Gallaghar and E. L. Saenger, Radium capsules and their associated hazards, Am. J. Roentgenol. Radium Therapy Nuclear Med. **77,** 511 (1957).
[6] R. J. Kennedy, H. O. Wyckoff, and W. A. Snyder, Concrete as a protective barrier for gamma rays from cobalt-60, J. Research NBS **44,** 157 (1950) RP2066.
[7] F. S. Kirn, R. J. Kennedy, and H. O. Wyckoff, Attenuation of gamma rays at oblique incidence, Radiology **63,** 94 (1954).
[8] R. T. Mooney and C. B. Braestrup, Attenuation of scattered cobalt-60 radiation in lead and building materials, AEC Report NYO 2165 (1957).
[9] National Academy of Sciences—National Research Council, Nuclear Data Sheets (1958).
[10] National Bureau of Standards Circular 499, Nuclear Data (1952).
[11] National Bureau of Standards Handbook 42, Safe handling of radioactive isotopes (1949).
[12] National Bureau of Standards Handbook 48, Control and removal of radioactive contamination in laboratories (1951).
[13] National Bureau of Standards Handbook 51, Radiological monitoring methods and instruments (1952).
[14] National Bureau of Standards Handbook 57, Photographic dosimetry of X- and gamma rays (1954).
[15] National Bureau of Standards Handbook 59, Permissible dose from external sources of ionizing radiation (1954); and 1958 Addendum.
[16] V. H. Ritz, Broad and narrow beam attenuation of Ir^{192} gamma rays in concrete, steel, and lead, Non-destructive Testing **16,** 269 (May-June 1958).
[17] Eugene L. Saenger et al., Emergency measures and precautions in radium accidents, J. Am. Med. Assoc. **149,** 813 (1952).
[18] N. Irving Sax, Dangerous properties of industrial materials, (Reinhold Publishing Corp., New York, N.Y., 1958).
[19] R. West, Low-energy gamma-ray sources, Nucleonics **11,** No. 2, 21 (1953).
[20] H. O. Wyckoff and R. J. Kennedy, Concrete as a protective barrier for gamma rays from radium, J. Research NBS **42,** 431 (1949) RP1983.
[21] U.S. Atomic Energy Commission, Standards for Protection Against Radiation, Title 10, Code of Federal Regulations, Pt. 20, U.S. Federal Register (January 29, 1957).
[22] U.S. Atomic Energy Commission, Handbook of federal regulations applying to transportation of radioactive materials (July 1955), AEC Division of Construction and Supply, Traffic Management Section, Washington, D.C.

Appendix A. Permissible RBE Doses

In April 1958, the National Committee on Radiation Protection and Measurements recommended certain permissible levels [15]. As interpreted for this Handbook, these recommendations are summarized in table 1.

TABLE 1. *Permissible RBE doses for organs*

	Average weekly dose [a]	Maximum 13-week dose	Maximum yearly dose	Maximum accumulated dose [b]
Controlled areas:	*rem* [c]	*rem* [c]	*rem* [c]	*rem* [c]
Whole body, gonads and blood-forming organs and the lenses of the eyes	0.1	3		[d] 5(N–18)
Skin of whole body (except skin of parts listed below)		10	30	
Hands and forearms, head, neck, feet, and ankles		25	75	
Environs:				
Any part of body	0.01		0.5	

[a] For design purposes. These values were obtained by dividing the average permissible yearly dose by 50.

[b] When the previous occupational exposure history of an individual is not definitely known, it shall be assumed that he has already received the full dose permitted by the formula 5(N–18).

Persons who were exposed in accordance with the former maximum permissible weekly dose of 0.3 rem and who have accumulated a dose higher than that permitted by the formula shall be restricted to a maximum yearly dose of 5 rems.

[c] The dose in rems may be assumed to be equal to the exposure in roentgens for gamma radiation, and equal to the absorbed dose in rads for beta radiation.

[d] N=age in years and is greater than 18.

Appendix B. Barrier Design Data and Computations

B.1. Table 2 indicates the type and energy of radiation emitted by the radionuclides considered here as well as the range of the emitted particles.

B.2. Table 3 gives occupancy factors, *T*, for different areas. These may be used as a guide in planning shielding when complete occupancy data are not available.

B.3. Table 4 gives data on radioactive sources of possible medical interest.

B.4. Table 5 gives structural shielding requirements for primary barriers, for scattered radiation and for leakage radiation around a cobalt-60 teletherapy unit. Attenuation data were obtained from figures 6, 8, and 9.

B.5. Tables 6, 8, and 10 gives structural shielding requirements for primary barriers, for scattered radiation and for leakage radiation around a cesium-137 teletherapy unit. Attenuation data were obtained from figures 6 and 8.

B.6. Table 7 gives the relation between distance and millicurie-hours for an exposure of 0.1 r from an unshielded source. Attenuation in air and possible scattering from nearby objects have been neglected.

B.7. Table 8 shows lead thicknesses required to reduce the radiation to 0.1 r; to reduce the radiation to 0.01 r, add 1 TVL.

B.8. The attenuation data in figures 6 to 12 were obtained under broad-beam conditions.

Figures 6, 7, and 8 give the transmission of gamma rays through concrete, iron, and lead.

Figures 9, 10, 11, and 12 give the transmission through concrete and lead of gamma rays scattered at the indicated angles.

B.9. Figures 11 to 19 give the relation between source output, distance, and barrier thickness to obtain a dose of 0.1 r in 40 hr. The transmission data of figures 6, 7, and 8 were used in computing data for these curves.

TABLE 2. *Radiations emitted by certain isotopes*

Radionuclide	Radiation [a]		Range [b]	
	Type	Energy	Air	Aluminum
		Mev	*cm*	*mm*
Radium series:				
Radium-226	Alpha	4.79, 4.61	3.1	
	Gamma	0.18		
Radon-222	Alpha	5.49	3.9	
Polonium-218 (radium A)	Alpha	6.0	4.5	
Lead-214 (radium B)	Beta	0.65		0.9
Bismuth-214 (radium C)	Gamma	0.053 to 0.35		
	Alpha	5.5	3.9	
	Beta	0.4 to 3.2		5.9
	Gamma	0.42 to 2.4		
Polonium-214 (radium C′)	Alpha	7.68	6.6	
Thallium-210 (radium C″)	Beta	1.96		4
	Gamma	0.297		
		0.78		
		2.36		
Lead-210 (radium D)	Beta	0.017		0.006
	Gamma	0.007 to 0.047		
Bismuth-210 (radium E)	Beta	1.17		1.9
Polonium-210 (radium F)	Alpha	5.3	3.6	
Cobalt-60	Beta	0.31		0.31
	Gamma	1.17, 1.33		
Cesium-137	Beta	0.51, 1.2		2.0
	Gamma	0.662		
		0.29		0.4
Gold-198	Beta	0.96		1.8
		1.37		3.0
	Gamma	0.412		
		0.676		
		1.088		
Iridium-192	Beta	0.672		1.2
	Gamma	Various, 0.136 to 1.065		
Tantalum-182	Beta	0.5		0.8
	Gamma	Various, 0.033 to 1.23		
Thulium-170	Beta	0.867		1.7
		0.950		1.9
	Gamma	0.084		

[a] A. D. Strominger et al., Rev. Mod. Phys. **30** 585 (1958).
[b] Braestrup and Wyckoff (1958) [1].

TABLE 3. *Occupancy factors*

(For use as a guide in planning shielding where adequate occupancy data are not available.)

Full occupancy $(T=1)$
Control space, offices, corridors, and waiting space large enough to hold desks, darkrooms, workrooms, shops, wards, nurses stations, rest and lounge rooms routinely used by occupationally exposed personnel, living quarters, children's play areas, occupied space in adjoining buildings.
Partial occupancy $(T=\frac{1}{4})$
Corridors too narrow for desks, utility rooms, rest and lounge rooms not used routinely by occupationally exposed personnel, wards and patients' rooms, elevators using operators, unattended parking lots.
Occasional occupancy $(T=\frac{1}{16})$
Closets too small for future occupancy, toilets not used routinely by occupationally exposed personnel, stairways, automatic elevators, outside areas used only for pedestrians or vehicular traffic.

Table 4. *Radioactive sources of medical interest*

Radioisotope	Atomic number	Half life	Gamma energy	Practical form	Production	Specific gamma ray emission
	Z		*Mev*			*r/curie hr at 1 m* [a]
Cesium-137	55	27y	0.662, 0.661	Sulfate	Fission	0.32
Chromium-51	24	28d	0.323	Metal	Reactor	[c] 0.018
Cobalt-60	27	5.2y	1.17 to 1.33	do	do	1.3
Gold-198	79	2.7d	5.412	do	do	0.23
Iridium-192	77	74d	0.136, 1.065	do	do	[c] 0.5
Radium-226	88	1622y	0.047 to 2.4	Sulfate	Natural	[b] 0.825
Tantalum-182	73	715d	0.33 to 1.2	Metal	Reactor	[c] 0.6
Thulium-170	69	129d	0.084	Oxide	do	[c] 0.004

[a] These values assume that gamma absorption in the source is negligible. Value in r/curie hr at 1 m can be converted to r/millicurie hr at 1 cm by multiplying by 10.

[b] This value assumes that the source is sealed within a 0.50 mm thick platinum capsule.

[c] These values are less certain and in some cases are estimates.

TABLE 5A. *Cobalt-60 shielding requirements for controlled areas* [a]

WUT [b]	Curies [c] approx.	Distance from source to occupied areas (ft)										
80,000	2000	5	7	10	14	20	28	40				
40,000	1000		5	7	10	14	20	28	40			
20,000	500			5	7	10	14	20	28	40		
10,000	250				5	7	10	14	20	28	40	
5,000						5	7	10	14	20	28	40
2,500							5	7	10	14	20	28
1,250								5	7	10	14	20
625									5	7	10	14
310										5	7	10

Type of barrier	Approx. HVL (cm)	Approx. TVL (cm)	Thickness of lead (cm)										
Primary	1.20	4.0	22.5	21.3	20.1	18.9	17.7	16.5	15.3	14.1	12.9	11.7	10.5
Secondary:													
Leakage [d] 0.1 %	1.20	4.0	10.5	9.3	8.2	7.1	6.0	4.7	3.4	2.0	0.6	0	0
0.05%	1.20	4.0	9.3	8.2	7.1	6.0	4.7	3.4	2.0	0.6	0	0	0
Scatter [e] 30°	1.02	3.40	12.15	11.10	10.10	9.05	8.00	7.00	6.00	4.95	3.95	2.95	1.95
45°	0.87	2.90	9.65	8.75	7.90	7.00	6.15	5.25	4.35	3.50	2.65	1.75	0.90
60°	0.75	2.50	7.65	6.90	6.15	5.40	4.65	3.90	3.15	2.4	1.65	0.9	0.25
90°	0.43	1.45	3.60	3.15	2.70	2.30	1.85	1.40	1.00	0.60	0.25	0.03	0
120°	0.20	0.65	1.45	1.25	1.05	0.85	0.65	0.45	0.30	0.15	0.05	0	0
150°	0.14	0.45	0.90	0.75	0.65	0.50	0.40	0.25	0.15	0.08	0.02	0	0

[a] For a weekly design level of 100 mr; add one tenth-value layer (TVL) for regions in the environs to reduce radiation to 10 mr/week.
[b] W=workload in r/week at 1 m, U=use factor, T=occupancy factor.
[c] Assumes use factor (U) and occupancy factor (T) are equal to one.
[d] Refers to leakage radiation of source housing; may be ingored if less than 2.5 mr/hr at 1 m in "on" position.
[e] For large field (20 cm diam) and a source-skin distance of 40 to 60 cm. This includes scattering from the collimator and from the phantom. (From Braestrup and Wyckoff [1].)

TABLE 5B. *Cobalt-60 shielding requirements for controlled areas* [a]

WUT [b]	Curies [c] approx.	Distance from source to occupied areas (ft)										
80,000	2000	5	7	10	14	20	28	40				
40,000	1000		5	7	10	14	20	28	40			
20,000	500			5	7	10	14	20	28	40		
10,000	250				5	7	10	14	20	28	40	
5,000						5	7	10	14	20	28	40
2,500							5	7	10	14	20	28
1,250								5	7	10	14	20
625									5	7	10	14
310										5	7	10

Type of barrier	Approx. HVL (in.)	Approx. TVL (in.)	Thickness of concrete (density 147 lbs/cu ft) (in.)										
Primary	2.6	8.6	47.5	45.1	42.7	40.3	37.8	35.4	32.9	30.5	28.0	25.6	23.1
Secondary:													
Leakage [d] 0.1 %	2.6	8.6	23.1	20.7	18.3	15.6	12.9	10.2	7.3	4.4	1.4	0	0
0.05%	2.6	8.6	20.7	18.3	15.6	12.9	10.2	7.3	4.4	1.4	0	0	0
Scatter [e] 30°	2.5	8.2	30.6	28.1	25.7	23.2	20.6	18.2	15.8	13.3	10.9	8.4	5.9
45°	2.4	8.0	27.0	24.6	22.2	19.8	17.4	15.0	12.6	10.2	7.8	5.4	3.0
60°	2.3	7.6	14.0	21.7	19.4	17.1	14.8	12.3	10.0	7.7	5.4	3.0	0.5
90°	1.8	6.2	16.9	15.0	13.2	11.4	9.6	7.8	6.0	4.1	2.1	0.1	0
120°	1.7	5.8	15.0	13.3	11.6	9.9	8.2	6.5	4.7	3.0	1.2	0	0
150°	1.5	5.0	12.5	11.0	9.6	8.1	6.6	5.1	3.7	2.2	0.8	0	0

[a] For a weekly design level of 100 mr; add one tenth-value layer (TVL) for regions in the environs to reduce radiation to 10 mr/week.
[b] W=workload in r/week at 1 m, U=use factor, T=occupancy factor.
[c] Assumes use factor (U) and occupancy factor (T) are equal to one.
[d] Refers to leakage radiation of source housing; may be ignored if less than 2.5 mr/hr at 1 m in "on" position.
[e] For large field (20 cm diam) and a source-skin distance of 40 to 60 cm. This includes scattering from the collimation and from the phantom. (From Braestrup and Wyckoff [1].)

Table 6A. *Cesium-137 shielding requirements for controlled areas* [a]

WUT [b]	Curies [c] approx.		Distance from source to occupied areas (ft)										
24,000	2000		5	7	10	14	20	28	40				
12,000	1000			5	7	10	14	20	28	40			
6,000	500				5	7	10	14	20	28	40		
3,000	250					5	7	10	14	20	28	40	
1,500	125						5	7	10	14	20	28	40
750								5	7	10	14	20	28
375									5	7	10	14	20
Type of barrier	Approx.		Thickness of lead (cm)										
	HVL (cm)	TVL (cm)											
Primary	0.65	2.1	10.5	9.9	9.3	8.6	8.0	7.4	6.7	6.1	5.5	4.8	4.1
Secondary:													
Leakage [d] 0.1 %	0.65	2.1	4.2	3.5	2.9	2.3	1.6	1.0	0.4	0	0	0	0
0.05%	0.65	2.1	3.5	2.9	2.3	1.6	1.0	0.4	0	0	0	0	0
Scatter [e] 35°	0.45	1.5	5.3	4.9	4.4	3.9	3.5	3.0	2.6	2.2	1.7	1.3	0.8
56°	0.38	1.3	4.1	3.7	3.3	2.9	2.5	2.1	1.7	1.4	1.0	0.7	0.4
90°	0.22	0.7	2.0	1.8	1.6	1.3	1.1	0.9	0.7	0.5	0.4	0.2	0.1
119°	0.13	0.4	1.0	0.9	0.8	0.7	0.6	0.5	0.3	0.2	0.2	0.1	0.03

[a] For a weekly design level of 100 mr; add one tenth-value layer (TVL) for regions in the environs to reduce to 10 mr/week.
[b] W=workload in r/week at 1 m, U=use factor, T=occupancy factor.
[c] Assumes use factor (U) and occupancy factor (T) are equal to one.
[d] Refers to leakage radiation of source housing; may be ignored if less than 2.5 mr/hr at 1 m in "on" position.
[e] For large field (20 cm diam) and a source-scatterer distance of 50 cm. This includes only scattering from an obliquely positioned flat scatterer.

Table 6B. *Cesium-137 shielding requirements for controlled areas* [a]

WUT [b]	Curies [c] approx.		Distance from source to occupied areas (ft)										
24,000	2000		5	7	10	14	20	28	40				
12,000	1000			5	7	10	14	20	28	40			
6,000	500				5	7	10	14	20	28	40		
3,000	250					5	7	10	14	20	28	40	
1,500	125						5	7	10	14	20	28	40
750								5	7	10	14	20	28
375									5	7	10	14	20
Type of barrier	**Approx.**		**Thickness of concrete (in.)**										
	HVL (in.)	**TVL (in.)**											
Primary	1.9	6.2	34.1	32.2	30.2	28.3	26.3	24.4	22.4	20.6	18.7	16.8	14.8
Secondary:													
Leakage [d] 0.1 %	1.9	6.2	14.8	12.9	11.0	9.1	7.0	4.9	2.0	0	0	0	0
0.05%	1.9	6.2	12.9	11.0	9.1	7.0	4.9	2.8	0	0	0	0	0
Scatter [e] 35°	1.8	6.1	23.4	21.6	19.8	18.0	16.2	14.4	12.5	10.7	8.8	7.0	5.1
56°	1.5	4.9	18.8	17.3	15.8	14.3	12.8	11.3	9.8	8.4	6.9	5.5	4.0
90°	1.4	4.7	16.3	14.9	13.5	12.0	10.6	9.2	7.8	6.4	5.0	3.7	1.9
119°	1.3	4.4	14.9	13.6	12.3	11.0	9.6	8.3	7.0	5.7	4.3	3.0	1.3

[a] For a weekly design level of 100 mr; add one tenth-value layer (TVL) for regions in the environs to reduce to 10 mr/week.
[b] W=workload in r/week at 1 m, U=use factor, T=occupancy factor.
[c] Assumes use factor (U) and occupancy factor (T) are equal to one.
[d] Refers to leakage radiation of source housing; may be ignored if less than 2.5 mr/hr at 1 m in "on" position.
[e] For large field (20 cm diam) and a source-scatterer distance of 50 cm. This includes only scattering from an obliquely positioned flat scatterer.

TABLE 7. *Relation between distance and millicurie-hours for an exposure of 0.1 r from an unshielded source*

Millicurie-hours	Distance to source				
	Radium	Cobalt-60	Cesium-137	Iridium-192	Gold-198
	ft	*ft*	*ft*	*ft*	*ft*
10	0.9	1.2	0.6	0.7	0.5
30	1.6	2.1	1.0	1.3	0.9
100	3.0	3.8	1.9	2.3	1.6
300	5.1	6.5	3.2	4.0	2.7
1,000	9.4	11.9	5.8	7.4	5.0
3,000	16.3	20.5	10.1	12.7	9.0
10,000	30.1	37.6	18.5	23.2	15.8

TABLE 8. *Protection requirements (in centimeters of lead) for various gamma-ray sources*

Millicurie-hours	Radium TVL[a]=5.5 cm lead			Cobalt-60 TVL[a]=4.1 cm lead			Cesium-137 TVL[a]=2.2 cm lead		
	Thickness of lead required to reduce radiation to 100 mr [b] at a distance of—								
	1 ft	3.2 ft	6.5 ft	1 ft	3.2 ft	6.5 ft	1 ft	3.2 ft	6.5 ft
100	4.0	0	0	5.0	0.7	0	1.1	0	0
300	6.2	1.5	0	7.0	2.8	0	2.1	0	0
1,000	8.9	3.6	1.1	9.1	4.9	2.5	3.3	1.1	0
3,000	11.3	5.8	3.1	11.0	6.8	4.4	4.3	2.1	0.8
10,000	14.1	8.5	5.5	13.1	8.9	6.5	5.4	3.2	1.9
30,000	16.7	11.0	7.8	15.0	10.8	8.4	6.4	4.2	2.9
100,000	19.5	13.7	10.5	17.2	12.9	10.5	7.5	5.3	4.0

Millicurie-hours	Iridium-192 TVL[a]=2.0 cm lead			Gold-198 TVL[a]=1.1 cm lead		
	Thickness of lead required to reduce radiation to 100 mr [b] at a distance of—					
	1 ft	3.2 ft	6.5 ft	1 ft	3.2 ft	6.5 ft
100	0.8	0	0	0.4	0	0
300	1.4	0.1	0	0.9	0	0
1,000	2.2	0.7	0.1	1.5	0.3	0
3,000	3.1	1.4	0.6	2.1	0.9	0.2
10,000	4.0	2.1	1.2	3.0	1.4	0.8
30,000	5.0	3.0	2.0	3.9	2.0	1.3
100,000	6.2	4.0	2.8	5.3	2.9	1.9

[a] Approximate value obtained with large attenuation.
[b] Add one tenth-value layer (TVL) to reduce radiation to 10 mr.

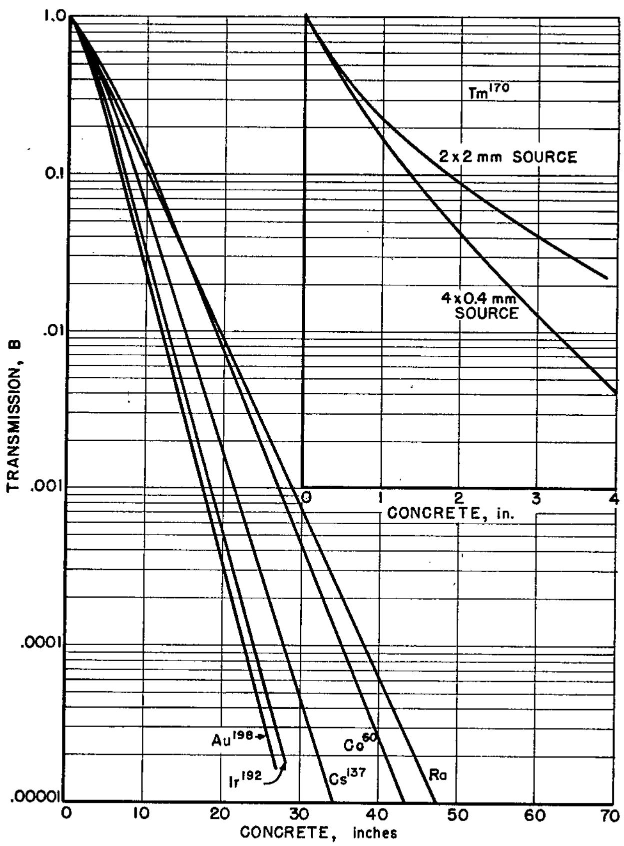

FIGURE 6. *Transmission through concrete (density 147 lb/ft³) of gamma rays from radium [20]; cobalt-60, cesium-137, gold-198 [7]; iridium-192 [16]; and thulium-170 [19].*

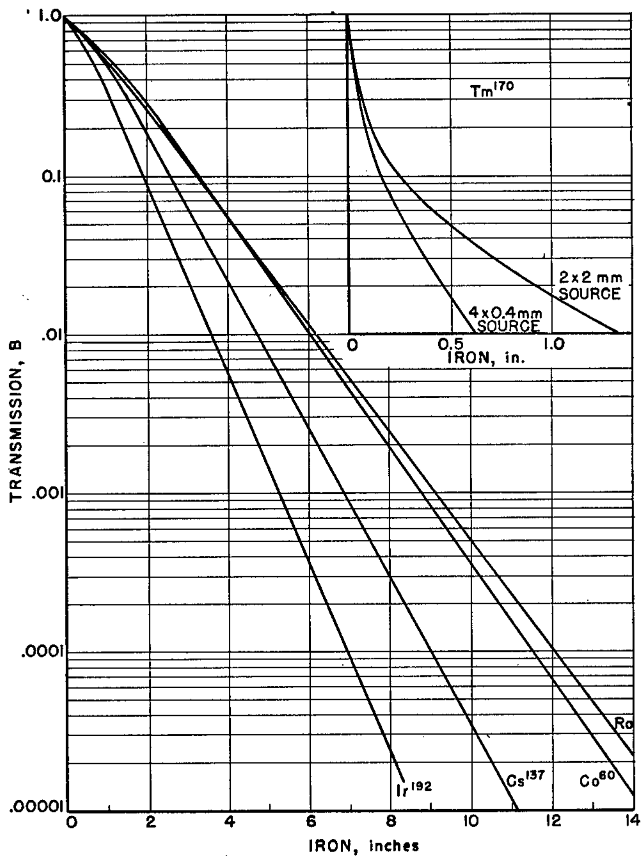

FIGURE 7. *Transmission through iron of gamma rays from radium [20]; cobalt-60, cesium-137 [7]; iridium-192 [16]; and thulium-170 [19].*

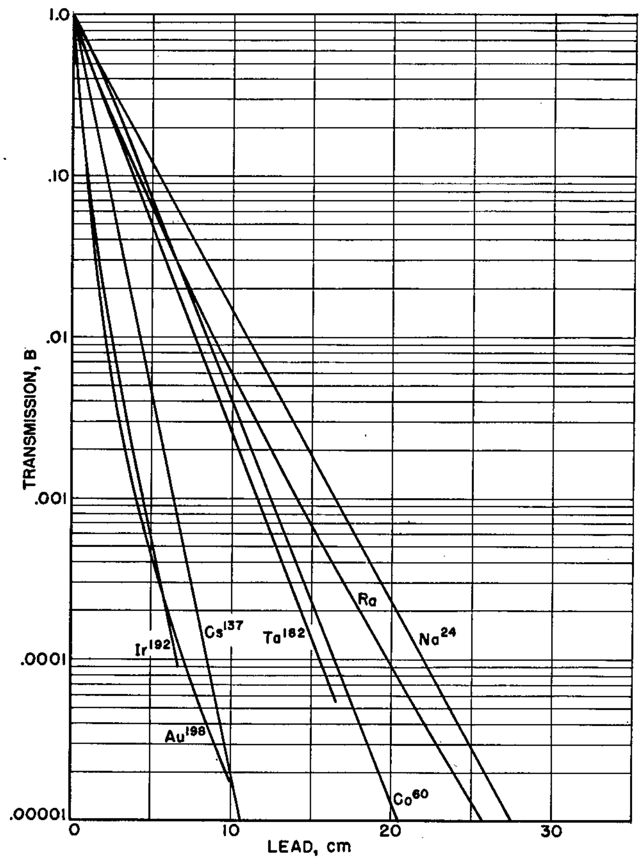

FIGURE 8. *Transmission through lead of gamma rays from radium [20]; cobalt-60, cesium-137, gold-198 [7]; iridium-192 [16]; tantulum-198 and sodium-24 [19].*

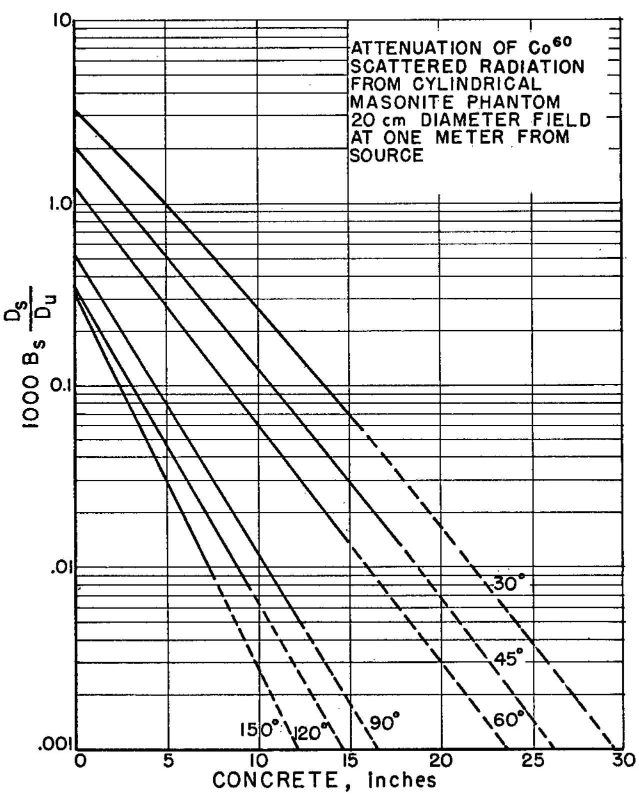

FIGURE 9a. *Attenuation in concrete (density 147 lb/ft³) of cobalt-60 scattered radiation from cylindrical masonite phantom [8].*

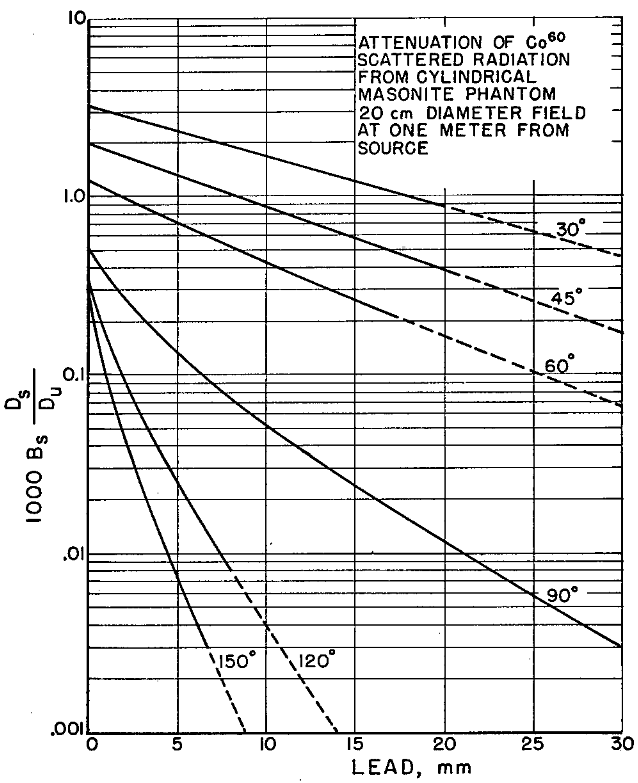

FIGURE 9b. *Attenuation in lead of cobalt-60 scattered radiation from cylindrical masonite phantom [8].*

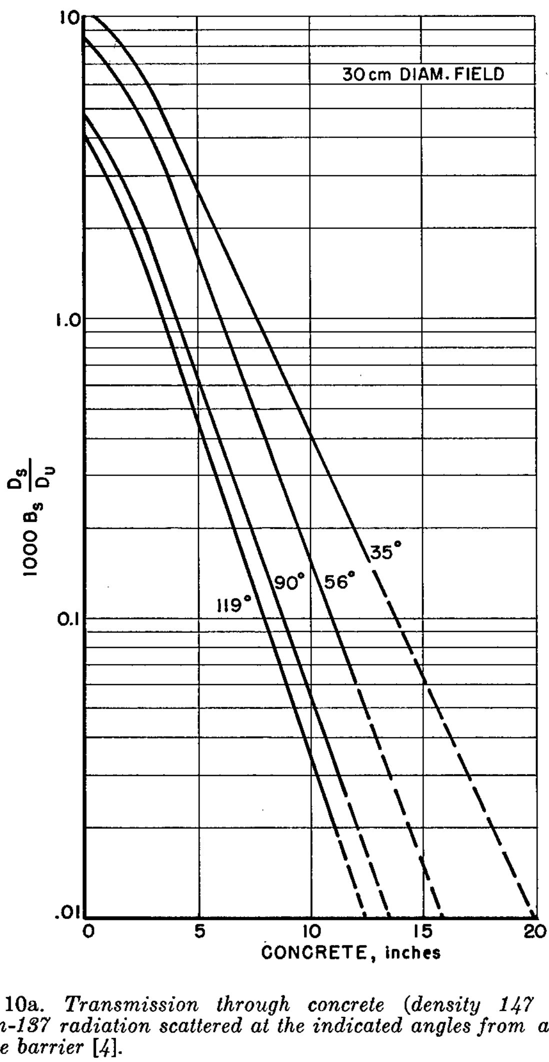

FIGURE 10a. *Transmission through concrete (density 147 lb/ft³) of Cesium-137 radiation scattered at the indicated angles from an oblique concrete barrier [4].*

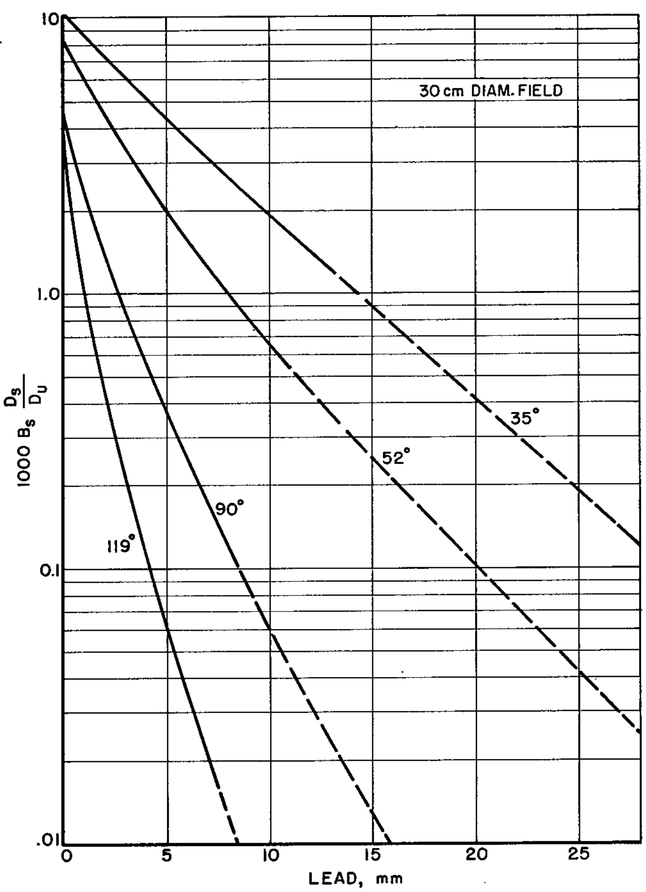

FIGURE 10b. *Transmission through lead of Cesium-137 radiation scattered at the indicated angles from an oblique concrete barrier* [4].

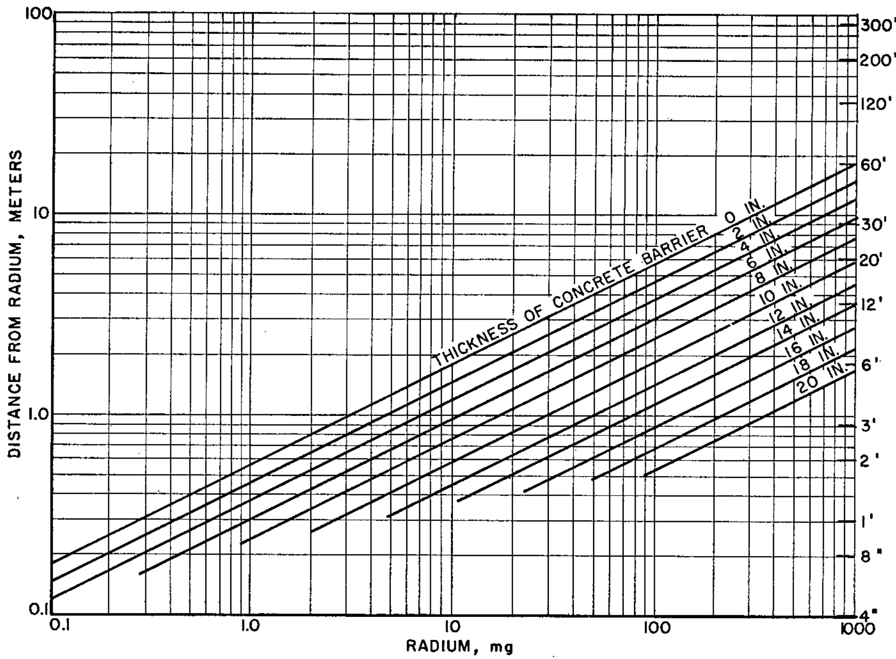

FIGURE 11. *Relation between amount of radium, distance, and shielding for controlled areas.*

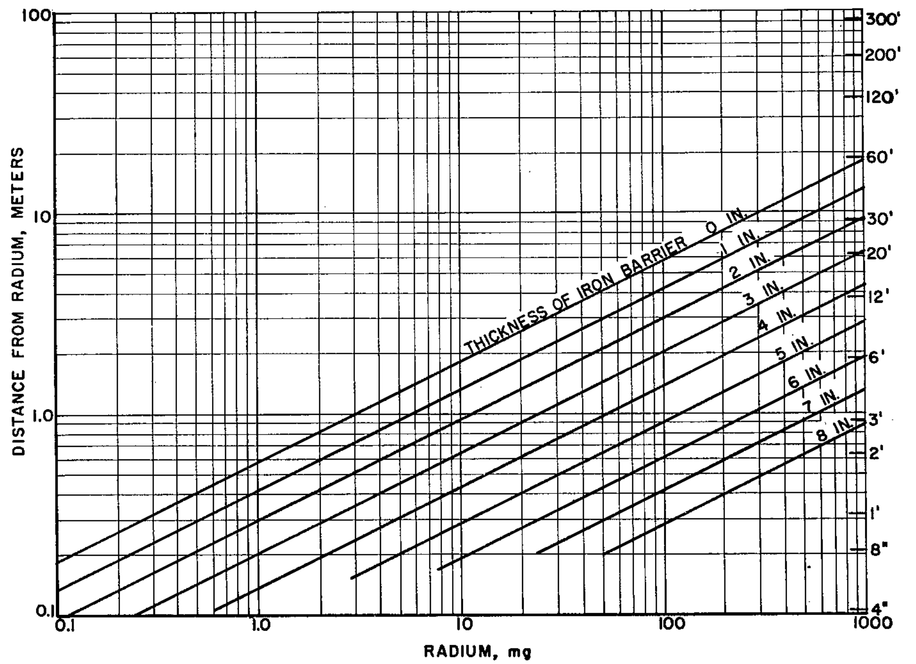

FIGURE 12. *Relation between amount of radium, distance, and shielding for controlled areas.*

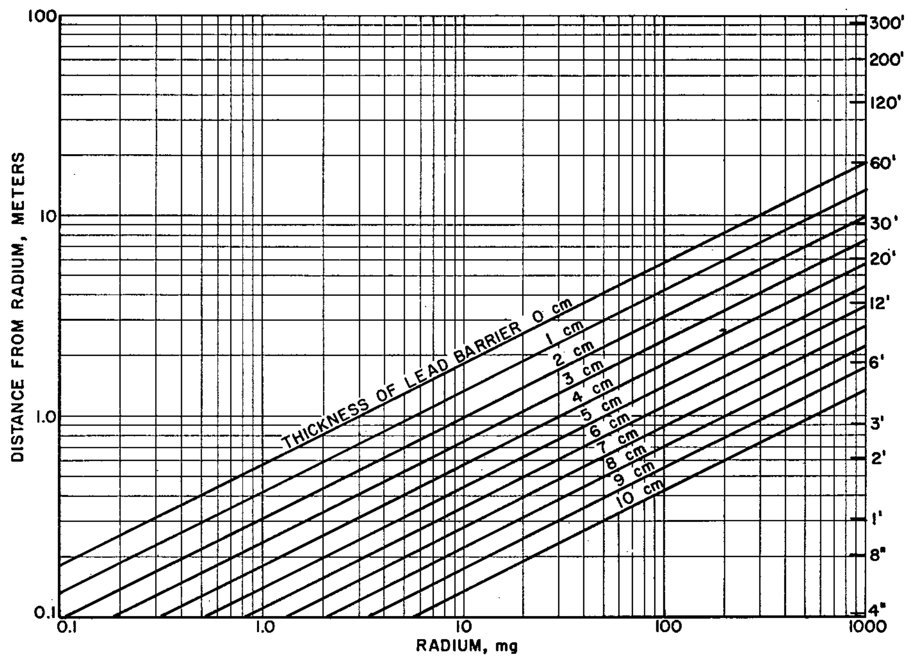

FIGURE 13. *Relation between amount of radium, distance, and shielding for controlled areas.*

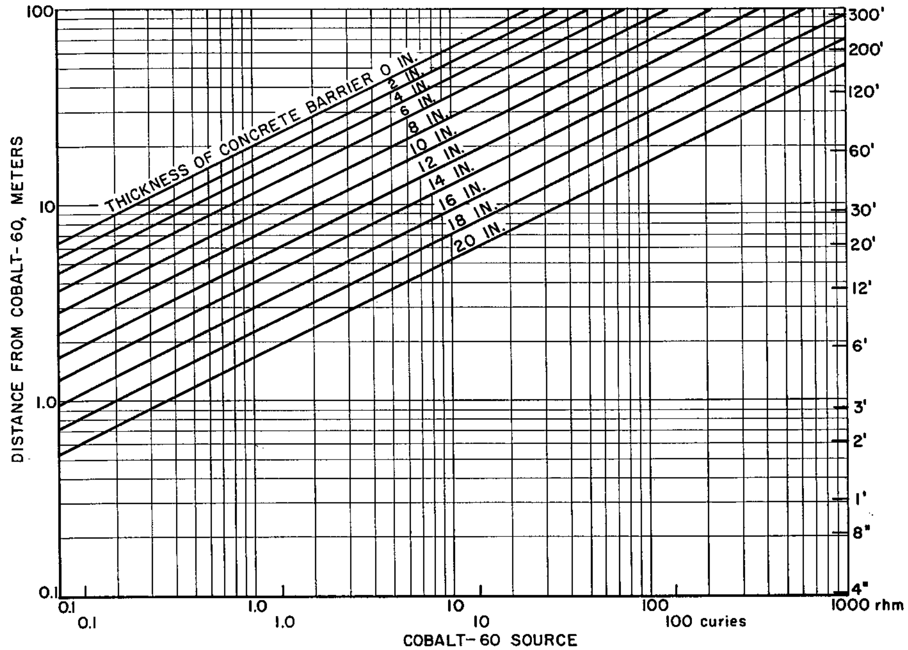

FIGURE 14. *Relation between rhm distance, and shielding for controlled areas.*

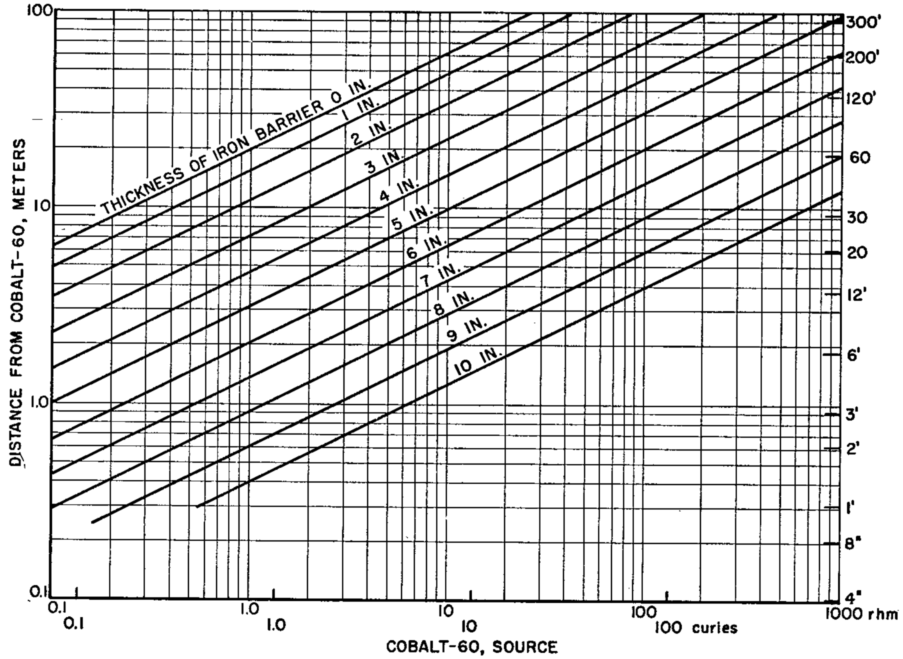

FIGURE 15. *Relation between rhm distance, and shielding for controlled areas.*

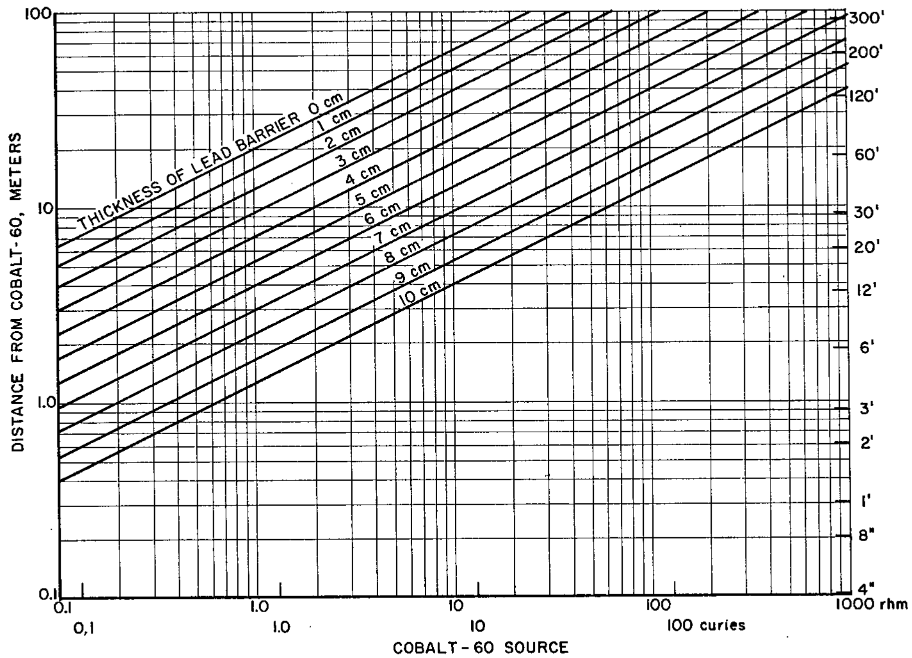

FIGURE 16. *Relation between rhm distance, and shielding for controlled areas.*

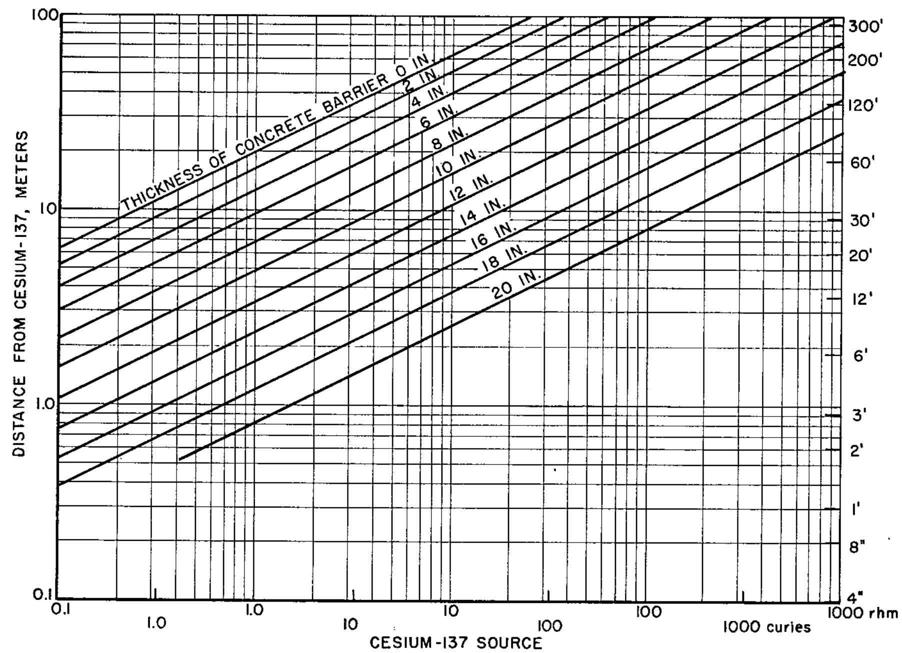

FIGURE 17. *Relation between rhm distance, and shielding for controlled areas.*

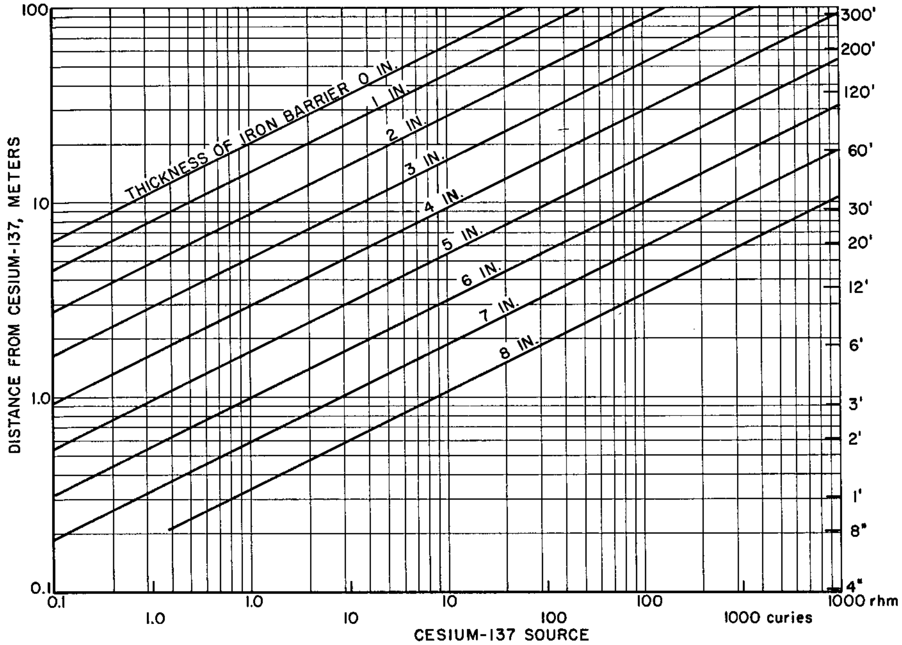

FIGURE 18. *Relation between rhm distance, and shielding for controlled areas.*

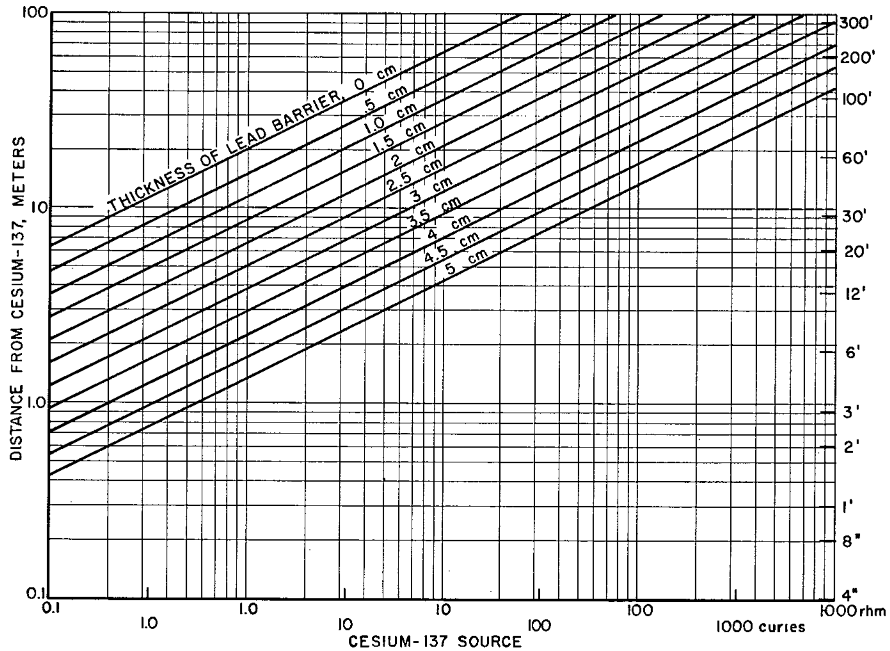

FIGURE 19. *Relation between rhm distance, and shielding for controlled areas.*

Appendix C. Encapsulation of Sources

C.1. Source Construction

C.11. The choice of capsule material depends upon the use to be made of the source and the characteristics of the radioactive material. The following items require consideration:

(a) External dimensions, to facilitate convenient use.

(b) Resistance to environmental effects. The capsule shall have sufficient strength and durability to withstand the mechanical stresses, pressure, temperature, and chemicals to which it will be subjected during use.

(c) Resistance to internal effects (i.e., chemical attack by radioisotope; carrier and binding agents; pressure buildup; and radiation damage).

(d) Filtering of radiation. The type and thickness of the capsule material will materially affect the available radiation by absorbing beta particles and weak gamma rays, and by production of bremsstrahlung. Capsules should be thick enough to filter out all unwanted particles.

C.12. Noble metals have been extensively used in the past for medical source capsules. Although they are highly resistant to corrosion and have a high density for shielding, they have poor structural qualities. Stainless steels have much better structural qualities and are replacing the noble metals to a great extent, especially for encapsulating cobalt–60.

Other base metals, such as aluminum and brass, are not usually used in medical sources due to their lack of corrosion resistance, but may be used in nonmedical sources.

C.13. Glass is exceptionally vulnerable to shock. Also, it is subject to devitrification and crazing from radiation. It is therefore not recommended for source capsules. All old glass capsules should either be reencapsulated or additionally encapsulated in a metal capsule.

C.14. Plastics are subject to hardening and cracking under irradiation. Therefore, they are not suitable for permanent source capsule materials except for very small calibration sources. Plastics may be used to temporarily protect or retain sources provided the plastic covering is not depended upon to prevent leakage of radioactive material. An example of such use is the placing of metal pellets in nylon tubing for interstitial use.

C.15. All radionuclides should be bound to prevent their rapid dispersal in event of capsule failure, unless thay are in the solid metallic form. Fusing in quartz or silica, and cold working in silver or gold matrix have proven successful for this purpose.

The radionuclide and any binding agents used should be free of moisture and organic compounds. Under irradiation these will form gases which can build up sufficient pressure to rupture a fairly strong capsule.

C.2. Sealing

C.21. All sources, except solid corrosion resistant metals and alloys shall be hermatically sealed within a capsule.

C.22. The seals shall be made in such manner that they have approximately the same physical strength as the rest of the capsule, and with materials having similar and compatible chemical and physical characteristics.

C.3. Labeling

C.31. Whenever physically possible, each source shall be labeled with the name or trademark of the manufacturer, a serial number, and the chemical symbol, mass number, and original activity of the isotope contained therein.

C.32. Labeling shall be applied by a permanent method such as engraving, die stamping, or etching directly on the capsule.

C.33. Whenever physical size makes labeling impossible, color coding or some other alternative method shall be used so that each source can be readily identified.

C.4. Testing

C.41. Each source shall be tested for external contamination after manufacture and before its use. If any contamination is detected, the source shall be thoroughly decontaminated and retested.

C.42. Each source shall be tested for adequacy of sealing prior to being used. If the radioisotope is deposited in a manner such that it would readily leak out if there were a break in the seal, it is sufficient to store the source for a period of time and check it for external contamination. However, if the radioisotope is in a form such that it would not leak out immediately, some other method shall be used which will clearly detect flaws in the seal. Metallic cobalt-60 is an example of such an isotope. Helium detectors and fluorescent dyes are capable of detecting flaws within safe tolerances.

C.43. All sources used for medical therapy shall be tested and certified as to type, energy, uniformity, and maximum output of radiation (the latter determined as accurately as possible).

Appendix D. Example of Emergency Procedures

The emergency procedures to be used in case of beam-control failure depends on the individual installation. The following is an example.

If signals indicate [15] that the beam-control system has failed to terminate irradiation at the preset time, the following steps are to be carried out:

1. Turn off main switch at control (unless this interferes with the removal of the patient).
2. Open the door to the treatment room.
3. If the patient is ambulatory, direct him to leave the room. If the patient is not ambulatory, enter treatment room, avoiding exposure to the useful beam as much as possible, and try to close the manual emergency beam control; if not immediately successful, remove the patient from the treatment room.
4. Close and lock the door.
5. Notify the radiation protection officer.
6. No attempt to repair equipment should be made by inexperienced persons.

Appendix E. Shipping Rules

The transportation of dangerous materials (including radioactive materials) in interstate commerce is regulated by the Interstate Commerce Commission, the Post Office Department, the Civil Aeronautics Board, and the United States Coast Guard. In addition, many States have enacted codes making these regulations applicable in intrastate commerce.

Pertinent excerpts can be found in the AEC Handbook of Federal Regulations Applying to Transportation of Radioactive Materials (22). The complete regulations can be found as follows:

Interstate Commerce Regulations. Title 49, Parts 71 to 78 of the Code of Federal Regulations (with supplements).

[15] Red signal stays on, and/or green signal does not light up.

Civil Aeronautics Board Regulations. "Transportation of Explosives and Other Dangerous Articles." Title 14, Part 49, Chapter I of the Code of Federal Regulations.

Post Office Department Regulations. Excerpts from Post Office Services Circular 2, December 1, 1954.

All the above are obtainable from the Superintendent of Documents, United States Government Printing Office, Washington 25, D.C.

Submitted for the National Committee on Radiation Protection and Measurements.

LAURISTON S. TAYLOR, *Chairman.*

WASHINGTON, February 8, 1960.

U.S. GOVERNMENT PRINTING OFFICE: 1960 O—544428